AL/HR-TR-1995-0202

ARMSTRONG LABORATORY

DESIGN CONSIDERATIONS FOR AN ON-SCREEN KEYBOARD

Laurie Quill

UNIVERSITY OF DAYTON RESEARCH INSTITUTE
CSERIAC PROGRAM OFFICE
AL/CFH/CSERIAC, Building 248
2255 H Street
Wright-Patterson Air Force Base, Ohio 45433-7022

HUMAN RESOURCES DIRECTORATE
LOGISTICS RESEARCH DIVISION
2698 G Street
Wright-Patterson Air Force Base, Ohio 45433-7604

July 1996

Final Technical Report for Period February 1993 to January 1995

Approved for public release; distribution is unlimited

AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation, or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this paper and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

CL Batchelor

CHERYL L. BATCHELOR
Task Monitor

B. W. C.

BERTRAM W. CREAM, GM-15, DAF
Chief, Logistics Research Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
July 1996

3. REPORT TYPE AND DATES COVERED
Final - Feb 1993 to Jan 1995

4. TITLE AND SUBTITLE
Design Considerations For An On-Screen Keyboard

5. FUNDING NUMBERS
C - DLA900-88-D-0393
PE - 62205F
PR - 1710
TA - D0
WU - 03

6. AUTHOR(S)
Laurie Quill

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Dayton Research Institute
CSERIAC Program Office
AL/CFH/CSERIAC, Building 248
2255 H Street
Wright-Patterson Air Force Base, Ohio 45433-7022

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB, OH 45433-7604

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/HR-TR-1995-0202

11. SUPPLEMENTARY NOTES

Armstrong Laboratory Technical Monitor: Cheryl L. Batchelor, AL/HRGO, DSN 785-2606

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This study tested & evaluated 3 on-screen keyboard arrangements with indirect input devices. In this study, finger placement & non-finger placement typists provided data for Stimulus Type (word vs. non-words), Input Devices (mouse vs. arrow keys), & Keyboard Arrangements (1-row alphabetical, 3-row alphabetical, & QWERTY). Data were collected on two movement tasks & a typing task. In the typing task, the user typed a given Stimulus Type using one of the On-Screen Keyboard Arrangements & Input devices. The movement tasks served as controls for movement time in the typing task. The QWERTY keyboard arrangement resulted in the fastest overall input times & was the most preferred arrangement overall. Analysis of the interaction between Input Device & Keyboard Arrangement for the unadjusted typing task times (before removing movement time) showed that when movement time was included, input times for the 1-Row Alphabetical were slower than the QWERTY for the Mouse condition; whereas, within Arrow Key condition, input times for the 1-Row Alphabetical & QWERTY were equivalent. This change in relative performance under the 1-Row Alphabetical arrangement for the Mouse condition can be simply attributed to movement time. After statistically removing the effects of movement time from the typing task, the 1-Row Alphabetical ... ement was equivalent to the QWERTY for both input device. Conclusions suggest potential inefficiency of movement control when using the Mouse w'th the 1-Row Alphabetical arrangement. Design which limit vertical movement of the indirect input device could provide more efficient movement time results with the 1-Row arrangement, thereby improving overall performance when using the 1-Row On-Screen Keyboard arrangement.

14. SUBJECT TERMS
input devices
indirect input devices
keyboard arrangement
keyboard design

15. NUMBER OF PAGES
108

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

CONTENTS

FIGURES

TABLES

PREFACE

This report provides user interface design considerations for portable maintenance aid platforms, such as those used for the Integrated Maintenance Information System (IMIS) developed by the Armstrong Laboratory Logistics Research Division at Wright-Patterson Air Force Base. Several groups and specific individuals made important contributions during the planning, development, and execution of this research. The Human Factors group at the Armstrong Laboratory Logistics Research Division (AL/HRGO), Wright-Patterson Air Force Base provided the inspiration, the necessary platform, and valuable input to this project. Additionally, various professors at the University of Dayton served on the master's thesis committee associated with this research. Specific members include David Biers, Ph.D., F. Thomas Eggemeier, Ph.D., William Moroney, Ph.D. and Leslie Whitaker, Ph.D. Human factors expertise was provided by the University of Dayton Research Institute under Contract No. DLA900-88-D-0393.

ABSTRACT

The purpose of the present study was to test and evaluate three on-screen keyboard arrangements with indirect input devices. Studies conducted for hard keyboard arrangements have considered various factors affecting typing; however, differences between the nature of the hard and on-screen keyboards tasks preclude extrapolation from hard keyboard studies to on-screen keyboard designs. In this study, finger placement and non-finger placement typists provided data for Stimulus Type (word vs. non-words), Input Devices (mouse vs. arrow keys), and Keyboard Arrangements (1-row alphabetical, 3-row alphabetical, and QWERTY). The primary data collection consisted of two movement tasks and a typing task. In the typing task, the user typed a given Stimulus Type using one of the On-Screen Keyboard Arrangements and Input Devices. Subjects then rated each keyboard arrangement on ease of use. The movement tasks served as controls for movement time in the typing task. At the conclusion of the study, users were asked to rank order their preference for keyboard arrangement and input device. The QWERTY keyboard arrangement resulted in the fastest overall input times and was the most preferred arrangement overall. Analysis of the interaction between Input Device and Keyboard Arrangement for the unadjusted typing task times (before removing movement time) showed that when movement time was included, input times for the 1-Row Alphabetical were slower than the QWERTY for the Mouse condition; whereas, within Arrow Key condition, input times for the 1-Row Alphabetical and QWERTY were equivalent. This change in relative performance under the 1-Row Alphabetical arrangement for the Mouse condition can be simply attributed to movement time. After statistically removing the effects of movement time from the typing task, the 1-Row Alphabetical arrangement was equivalent to the QWERTY for both input devices. Conclusions suggest potential inefficiency of movement control when using the Mouse with the 1-Row Alphabetical arrangement. Designs which limit vertical movement of the indirect input device could provide more efficient movement time results with the 1-Row arrangement, thereby improving overall performance when using the 1-Row On-Screen Keyboard arrangement.

INTRODUCTION

Various applications have required the use of on-screen keyboards. These applications include video games; video cameras; and computerized field devices, such as portable maintenance aids (Thomas & Clay, 1988). Indirect pointing devices, such as a mouse, joystick, or arrow keys have been used in these applications due to logistical problems associated with using direct pointing devices (e.g., touch screen or stylus). For the purposes of this study, the on-screen keyboard was defined as allowing a user to input alphabetical information onto a display screen via an indirect pointing device with a select function (a mouse incorporating a point and click action; or arrow keys with a select key incorporating a move and select action). Pointing and selecting various regions on the screen (labeled with alphabetical characters) resulted in the display of the corresponding alphabetical character.

The purpose of the present study was to test and evaluate alternative on-screen keyboard arrangements with indirect input devices. On-screen keyboards are often arranged in the same configurations as hard keyboards. However, previous evaluations of keyboard arrangements have focused on the hard keyboard and issues relevant to the hard keyboard. Evaluation results of hard keyboard arrangements do not necessarily apply to on-screen arrangements, due to differences in the methods used to carry out task requirements.

Keyboard tasks (hard and on-screen) require both psychomotor (i.e., response movement activities) and cognitive (i.e., cognitive activities) subtasks. The methods used to carry out each of these subtasks differ for hard and on-screen keyboards. The differences in methods are fairly obvious for the psychomotor subtasks. For the cognitive subtasks, the hard keyboard typing task does not require *visual* location of the keys for many typists; whereas, the on-screen keyboard requires visual location of keys for all typists.

In the present study, some of the issues associated with the traditional hard keyboard design were applied to several on-screen keyboard designs. The issues were applied to determine whether the variables associated with hard keyboard tasks would similarly effect on-screen keyboard tasks. The variables were manipulated to include both response movement and cognitive activities for the on-screen keyboard. The results of the present study were compared with results of previous hard keyboard studies.

Hard Keyboard Studies

Response movement and cognitive activities associated with hard keyboard designs have been studied extensively. A review of these studies reveals at least two differences in the nature of tasks associated with hard keyboard versus on-screen keyboard use. These two differences preclude direct extrapolation from studies using hard keyboard arrangements to the design of on-screen keyboard arrangements. First, the hard keyboard task requires different response movement activities than the on-screen task. Secondly, the hard keyboard task is only visual for hunt-and-peck or non-finger placement typists; whereas, the on-screen task is cognitively different since it is primarily visual for all users.

The first factor preventing generalizations from hard keyboard studies to on-screen tasks concerns the response movement activities required for the tasks. On a hard keyboard, moving the fingers among the three rows of letters is a quite different action from moving the fingers among four directional arrow keys and pressing a select function to "accept" a letter (the latter, on-screen keyboard method being slower).

Originally, hardware constraints imposed on hard keyboards forced designers to focus on minimizing hand and finger motion and the jamming of typebars. Studies in hard keyboard arrangements, therefore, have traditionally considered either response movement, or hardware constraints, or both, as they effect overall efficiency and effectiveness of typing.

Numerous studies have been conducted using and comparing the efficiency and effectiveness of various hard keyboard arrangements (Hirsch, 1970; Michaels, 1971; Kinkead, 1975; Norman & Fisher, 1982). In these studies, the traditional QWERTY keyboard resulted in better overall typing performance than alternative alphabetical arrangements. This keyboard, designed by Sholes, is named for the arrangement of the first 6 letters on the top row, left side of the keyboard-- Q, W, E, R, T, and Y.

Norman and Fisher (1982) compared several hard keyboard layouts, including a Sholes QWERTY, Dvorak DSK, random, and four alphabetical arrangements. Their findings were similar to findings by Alden, Daniels, and Kanarick (1972) and Kinkead (1975) in which typing performance on the QWERTY-style arrangement was significantly better than on the alphabetical arrangements. Even studies with untrained typists, such as the one conducted by Hirsch (1970), have shown that the standard QWERTY-style hard keyboard arrangement resulted in faster and more accurate data entry than an alphabetically-arranged keyboard.

Of the hard keyboard arrangement alternatives, the Dvorak DSK has been shown to be a viable alternative to the QWERTY keyboard. However, in the process of choosing which keyboard arrangements to use in the present study, two factors were considered in determining whether or not to include the Dvorak arrangement. First, the Dvorak DSK keyboard layout was designed to minimize hand and finger motion associated with typing (a separate key was provided for each letter of the alphabet, as in the QWERTY arrangement). Although it was found to be slightly faster than the QWERTY arrangement (Kinkead, 1975), these types of hand and finger motions (i.e., separate hard keys for each letter) are not considerations in the design of an on-screen keyboard. Second, user familiarity with this arrangement is severely limited, especially compared to the QWERTY and alphabetical arrangements. Due to these two factors, the Dvorak DSK keyboard was not included in the present study.

Like the Dvorak, the QWERTY and alphabetical arrangements have traditionally been built in three or four rows to minimize hand and finger movements. However, minimizing hand and finger movements for an on-screen task does not necessarily require a three- or four-row configuration. This hypothesis permits presentation of an alphabetical arrangement on a single row.

The second factor limiting the probability that generalizations can be made from hard keyboard to on-screen tasks is based on the visual nature of the task. A finger placement typist (on a hard keyboard) generally does not look at the keys; therefore, the task cannot be considered a "visual task." However, an on-screen keyboard task, even for a finger placement typist, is a visual task. This is clearly a cognitive difference between the hard keyboard and on-screen tasks for the finger placement typist.

In addition to visually locating keys, other mental visualizations may also effect keyboard arrangement tasks. Norman and Fisher (1982) indicated a potential compatibility problem between the mental computations required for visualizing positioning of letters in the alphabet and then physically locating the letter on 3-row alphabetical arrangements. The compatibility problem dealt with the notion that positioning letters in the alphabet was not visualized in 3 rows, but rather in a linear fashion ("A" to "Z"). The user was required to switch from a linear conceptualization of the alphabet to a 3-row presentation. This was thought to slow the cognitive time required to perform the task when using the 3-row alphabetical arrangements (3-row arrangements were used exclusively in their study). Amell, Ewry, and Colle (1988) expanded on this notion by stating that there is more compatibility and therefore, enhanced learning and operating speeds, if keyboards readily map to natural human cognitive processes. The potential differences in the cognitive activities of visual searching and visualizations of characters for hard versus on-screen arrangements required further study; therefore, an analysis of cognitive activities was included in the present study.

Although studies using the hard keyboard have shown the advantage of the QWERTY style over an alphabetical arrangement, differences in response movement and cognitive activities for the on-screen task may not permit replication of hard keyboard study results. That is, generalizations from research done for hard keyboards to situations using on-screen keyboards may not be legitimate. Factors such as differences in response movement and cognitive activities are examples of why differences were predicted for the current study.

The purpose of the present study was to assess the empirical factors affecting the on-screen keyboard task, especially as they related to the results of hard keyboard studies (i.e., Are the results of the hard keyboard studies applicable to the on-screen keyboard task?). Four independent variables were chosen to assist in addressing response movement and cognitive activities of the on-screen task: On-Screen Keyboard Arrangement, Input Device, Stimulus Type, and Typing Method. The variables were also manipulated in previous hard keyboard studies, thereby making comparisons between hard and on-screen keyboard arrangements easier. On-Screen Keyboard Arrangement and Input Devices were included to address response movement activities, while On-Screen Keyboard Arrangement and Typing Method were included to address cognitive activities of the task. Stimulus Type was added to assist in generalizing study results to a variety of on-screen typing applications.

On-Screen Keyboard Arrangements

Presuming that a generalization from hard keyboard studies cannot be applied to on-screen keyboard applications, manipulation of keyboard arrangement became a necessary variable in the present study. Hard keyboard studies have, traditionally, manipulated arrangement of letters on the keyboard as a variable (Hirsch, 1970; Kinkead, 1975; Michaels, 1971; Norman & Fisher, 1982). One common hypothesis in many of these studies was that some keyboard arrangements might be easier to cognitively process than other arrangements. As stated earlier, Norman and Fisher (1982) noted that it could be easier to process a keyboard arranged alphabetically in 1-row than a standard QWERTY arrangement. Due to the arrangements hypothesis made in these studies, it was necessary to assess both 3-row and 1-row arrangements for the on-screen study.

Three different styles of on-screen keyboard arrangements were incorporated into the present study: the standard Sholes (QWERTY) keyboard; a straight alphabetical keyboard (1-Row Alphabetical); and a 3-Row, horizontal, alphabetically arranged keyboard (see Figure 1. Keyboard Arrangements).

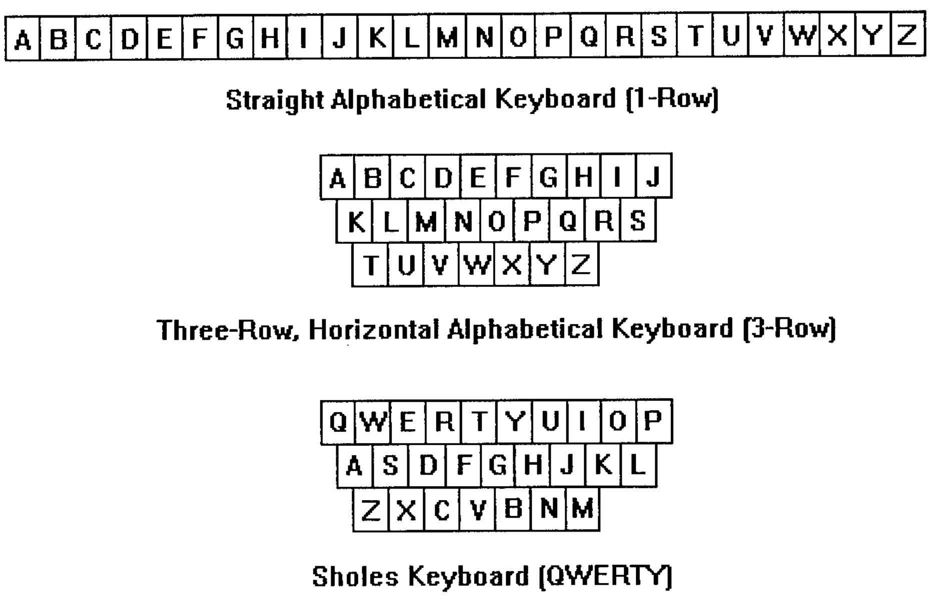

Figure 1. Keyboard Arrangements

Since the QWERTY keyboard arrangement is familiar to many people, and would assist some users in producing faster response times, it required inclusion as a keyboard arrangement to be assessed. The straight or 1-Row Alphabetical keyboard is similar to arrangements often found on video games, and follows Norman and Fisher's (1982) logic of a linear conceptualization of the alphabet. The QWERTY arrangement and keyboard arrangements similar to the 3-Row, horizontal, alphabetically-arranged keyboard have been used in previous hard keyboard studies (Hirsch, 1970; Michaels, 1971; Norman & Fisher, 1982). For the on-screen task, the 3-Row Alphabetical arrangement had the advantage over the 1-Row Alphabetical

arrangement because the movement time required to go from key to key presumably would be less. Additionally, the 3-Row Alphabetical arrangement was included in this study to provide insight as to whether it was the letter arrangement (alphabetical versus QWERTY) or the number of rows (1 versus 3) which made a difference in performance [this was mentioned 4 paragraphs earlier].

Input Devices

Input devices can be categorized into two classifications: direct pointing devices and indirect pointing devices. The application of a direct pointing device (such as a touch screen or stylus) is limited in certain environments or with certain interfaces due to logistical problems, such as screen size. Therefore, although studies have shown and reviews have concluded that these devices do result in better performance (Goodwin, 1975; Karat, McDonald, & Anderson, 1986; Greenstein, & Arnaut, 1988), they were not assessed in the present study. Studies and reviews of indirect pointing devices (which can be used in a variety of environments and with a variety of interfaces) have frequently used or addressed the use of keypads (arrows) and mice (Card, English, & Burr, 1978; Greenstein, & Arnaut 1988). The current study manipulated a mouse and a keypad as one independent variable in an attempt to collect data concerning the response movement associated with each of these input devices.

In a study by Card, English, and Burr (1978), the mouse was the most efficient means of indirect pointing, while the keypad was the least efficient. In the current study, these two input devices were compared to hard keyboard tasks and differences among various keyboard arrangements for on-screen keyboard tasks were measured in relation to the input device used.

Typing Method

As mentioned earlier, a finger placement typist using a hard keyboard is not engaging in a visually-oriented typing task; however, a non-finger placement typist using a hard keyboard is performing a visually-oriented task. A typist who uses a finger placement method is, typically, a skilled typist. On the other hand, a typist who relies on a hunt-and-peck method of typing (a non-finger placement typist) is, generally, a novice typist. Both the finger placement and the non-finger placement typist are familiar with the alphabet; however, finger placement (skilled) typists generally have more experience with the QWERTY arrangement. Therefore, for a hard keyboard task, the skilled typist does not need to visually observe the QWERTY arrangement when typing.

Typing skill has been a variable commonly used to assess hard keyboard arrangements. In a study by Michaels (1971), three typing skill levels (high, medium, and low) were assessed for various hard keyboard arrangements, including a 3-row alphabetical and a QWERTY-style hard keyboard arrangement. Results from Michaels' study showed that typing was faster and more accurate on the QWERTY keyboard for both medium- and high-skilled typists; however, there was no

significant difference for low-skilled typists between the alphabetical and QWERTY style keyboard arrangements.

If these results are applied to an on-screen keyboard task, one would expect Finger Placement typists to perform better on the on-screen QWERTY keyboard, while Non-Finger Placement (novice) typists would show no significant differences among the three keyboard arrangements. Given that the nature of the on-screen task is visual for all typists and only visual for Non-Finger Placement typists in the hard keyboard task, it was hypothesized that results from the hard keyboard task may not be applicable to the on-screen task.

Stimulus Type (Words versus Non-Words)

Stimulus Type was added to the present study to assist in generalizing study results to a variety of on-screen typing applications. As with the other variables chosen for this study, Stimulus Type has also been manipulated in hard keyboard evaluations. Hirsch (1970) identified that typing performance using less meaningful material, such as part numbers or non-words, could yield different results from actual, recognizable words.

There are many applications for various types of information (words and non-words). For example, on a computerized aiding system input might be required for a small amount of text, such as a part number. This type of string is not pronounceable and generally not committed to memory. Stimulus Type, therefore, required study to determine whether it interacted with On-Screen Keyboard Arrangements, Input Devices, or Typing Method.

In manipulating words versus non-words, it is important to control both which characters are used and number of characters used. Gibson, Pick, Osser, and Hammond (1962) studied words versus non-words. An interesting control employed by Gibson et al. was the use of real words spelled backwards so that paired combinations ("glass" and "ssalg") would not be confounded by other factors, such as characters used and number of characters used. This control was incorporated into the present study.

Present Study

The present study incorporated four independent variables: Keyboard Arrangement, Input Device, Typing Method, and Stimulus Type. These variables were used to assist in providing design guidelines for on-screen keyboards. Manipulation of the variables provided data to assess response movement and cognitive activities. However, in order to separate these two aspects of the typing task, a unique experimental paradigm was developed.

A potential confound was identified in the keyboard arrangements selected for the present study. This confound was the time required to move the cursor from one selectable item to another. On the QWERTY arrangement, movement of the cursor from the "A" to the "Z" key was short, approximately 1/2" from target center to target center. On either of the alphabetical arrangements, moving from the "A" to the "Z" key meant moving the cursor from one extreme end of the keyboard to the opposite

end, approximately 8-3/4" from target center to target center on the 1-Row Alphabetical arrangement. The confound was addressed by separating response movement from cognitive activities in the on-screen keyboard task. Without this control paradigm, differences found among the keyboard arrangements could have been due to either, (1) the response movement alone, or (2) the response movement and some cognitive requirements imposed by the keyboard arrangement.

To differentiate between the time required to move the cursor and the time required to make a decision and respond to the alphabetical information displayed, the study incorporated a multi-task approach. A typing task served as the primary experimental task, incorporating response movement and cognitive activities, and two movement tasks served as a control for response movement time.

In the experimental task, the user typed a given word or non-word utilizing one of the Keyboard Arrangements and Input Devices. When a stimulus appeared on the screen, the user's task was to type the letters in the appropriate sequence. For each letter, this involved locating the appropriate letter, moving to the box containing that letter, and selecting it. This sequence involved both response movement and cognitive activities.

The movement tasks were identical to the experimental task with the exception that the boxes representing the keyboard arrangements did not contain letters. Boxes were highlighted in a sequence equivalent to the letter position of the word or non-word stimulus to which they were yoked. Using this paradigm, independent assessments could be made for movement task times, cognitive task times, and movement and cognitive task times.

METHOD

Design

The present study was a Typing Method (Finger Placement vs. Non-Finger Placement) X Keyboard arrangement (QWERTY, 1-Row Alphabetical, 3-Row Alphabetical) X Input Device (Mouse vs. Arrow Keys) X Stimulus Type (Words vs. Non-Words) mixed design. Typing Method was manipulated between-subjects and the remaining three variables were manipulated within-subjects. Four dependent measures were obtained: input times, errors, subjective measures of ease of use, and subjective preferences.

Subjects

Twenty-four introductory psychology students from the University of Dayton served as subjects. All participants were right handed (see Appendix A for the Biographical Data Sheet used). Students were required to participate in psychological studies as part of their introductory psychology curriculum; therefore, they received course credit for their participation. Subjects signed up for the study under one of two Typing Method categories-- Finger Placement typist or Non-Finger Placement typist (n = 12 per category). Each category's sign-up sheet had written Typing Method descriptions at the top of the sign-up sheet, and these descriptions assisted in discrimination between the two Typing Methods (see Appendix B).

Prior to beginning the experimental paradigm, each subject was given a minimum of three, two-minute standard typing tests on a standard hard keyboard to verify the Typing Method used (see Appendix C). During the typing test, a list of criteria were checked by the experimenter to assure that each subject employed the appropriate Typing Method (finger placement or non-finger placement). If subjects did not meet the criteria (see Appendix D), they were reassigned to the other method or excused. One subject was reassigned from the finger placement to non-finger placement method, and one subject was excused when an appropriate category could not be determined. Each subject used in the study was required to complete at least one typing test with five or fewer errors.

Apparatus

Hardware

A 20 MHz, IBM-compatible, 386 computer with a VGA monitor was used for the development and for the actual experiment. The computer provided two Input Devices: a two-button mouse with a single click (select) capability and the inverted T arrow keys with a select key. Autorepeat on arrow keys remained at the standard or recommended settings for MS DOS-compatible keyboards.

Software

The software driving the presentation, graphics, millisecond timing, mouse and keyboard drivers, and input and output files was written in C++. A standard library was used for the graphics, timing, mouse, and keyboard drivers. The interface was developed as a Microsoft Windows application.

The customized software presentation included a Display Viewport, a Keyboard Viewport, an Input Viewport, and a Home Base Viewport (see Figure 2. Viewport layout). The stimulus to be typed was presented in the Display Viewport. The three Keyboard Arrangements were independently displayed in the Keyboard Viewport. Information being typed by the subject was displayed in the Input Viewport. Upon initiating each trial, the pointer or cursor was located in the Home Base Viewport.

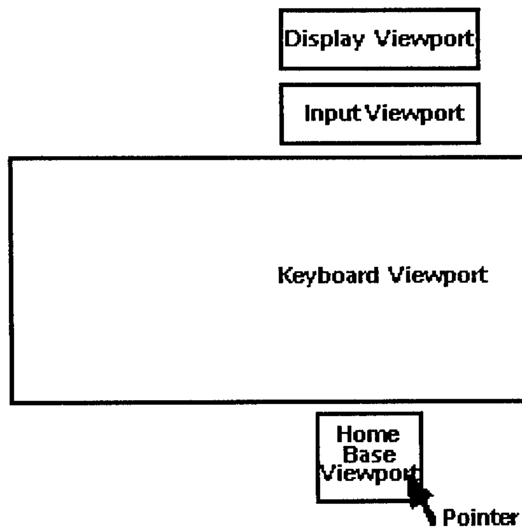

Figure 2. Viewport layout

Materials

On-Screen Targets

Determination of an appropriate size for the on-screen targets was a consideration addressed for response times. Movement time is affected by distance (as distance increases, movement time increases) and target size. Movement time is decreased as the target size (required accuracy) is increased (Boff and Lincoln, 1988). Given the task constraints , such as screen size and on-screen keyboard arrangement, the targets were approximately 1/3" square for each keyboard arrangement (the exact size of the targets was the same for each arrangement).

Stimulus Type

Six different stimulus sets were constructed. Within any one set there were twelve stimuli: six words and six non-words (see Appendix E). The six words within any given stimulus set were from four to seven characters in length. The cumulative character count for these six words was 33 characters. Among these 33 characters, each letter of the alphabet was used at least once. Therefore, among the six stimulus sets 26 letters (A through Z) were used at least once in each set. Seven letters (mostly vowels) were used repeatedly, and these seven letters varied among the six stimulus sets. All of these criteria were used to increase similarity among the stimulus sets.

Construction of the six non-words within any given stimulus set was accomplished by taking the six words from the stimulus set and reversing the letters of each word ("glass" was changed to "ssalg").

Subjective Scales

Two types of subjective scales were given to participants. The overall purpose of these evaluation techniques was to obtain subjective assessment opinions of the three within subject variables, interactions among ratings given to these variables, and Keyboard Arrangement and Input Device preferences. A bipolar rating scale (Meister, 1986) was used after the subject had completed the Experimental Task with one of the three Keyboard Arrangements (the Block Questionnaire). This scale was primarily used to compare subjective opinions of the three within-subject variables and to compare interactions among ratings with results from the reaction time tasks. This subjective assessment also included statements on topics such as those identified in Williams & Leaf (1986);such as ease of use overall, density of targets, size of target, ease of use with each device, etc. (see Appendix F). A rank order scale was used at the end of test to establish an hierarchical order of preference for the Keyboards and Input Devices (see Appendix G).

The bipolar rating scale was constructed by making statements concerning the ease of use ("Hard" versus "Easy") of each of the On-Screen Keyboard Arrangements and Input Devices with each other, with words, with non-words, and altogether. There were also two statements concerning the density and size of the letters presented ("Bad" versus "Good"). The scale was a seven category, bipolar scale ranging from 1 to 7.

The rank order scale simply restated the six conditions experienced by the subject (for example., on-screen QWERTY Keyboard arrangement using the Mouse Input Device), and requested that the subject assign a rank order (from 1 to 6) next to each condition. The six conditions (factorial combination of the three combinations and the two Input Devices) were presented in the order in which the subject received them (i.e., there were six questionnaires, each one in a different order, and each subject received the questionnaire which matched the order in which they received the conditions).

Procedure

Subjects participated on two separate days. On Day 1, half of the subjects within each Typing Method used one device (Mouse or Arrow Keys) while the other half used the other device. On Day 2, subjects performed the same on-screen procedures as in Day 1, with the alternative Input Device.

On a given day, the subject participated in five on-screen tasks: a selection task, a movement practice task, a movement task, a typing task, and the repeat of the movement task. Conditions were identical on the two days, with the exception that on Day 1 subject participation began with a brief overview of the general nature and purpose of the study and the hard keyboard typing test. Instructions on how to complete each task were read to the subjects prior to beginning each task (see Appendix H).

Practice Tasks

Selection Task. The purpose of the Selection Task was to familiarize the subject with how to activate the given input device. The task lasted for 1 minute, and began when

the subject clicked the left mouse button or pressed the "Enter" key for the first time. During this one minute time period, the subject received twelve randomly-timed cues. The cue was the Display Viewport highlighting (turning reverse video). Upon perceiving each cue, the subject had been instructed to click the left mouse button or press the "Enter" key (whichever device is being used that day), as quickly as possible. Reaction times were recorded for the duration between the initiation of each cue and the release of the mouse button or select key.

Movement Practice Task. The Movement Practice Task familiarized the subject with how to move the pointer around the screen using the Input Device. The subject was presented six trials divided such that the number of movements for any trial ranged from four to seven (the first trial provided five movements, the second provided six movements, etc.). Total movements over the six trials was 33. This arrangement (6 trials and 33 total movements) corresponded to exactly one-half block in the Movement and Experimental Tasks.

The Movement Practice Task was entirely self-paced, and began when the pointer is positioned on the Home Base Viewport (no other viewports were displayed). The user pressed the select function key (mouse click or select key) to start the first trial. A selectable region, the same size as those to used in the Movement and Experimental Tasks, appeared somewhere above the Home Base Viewport on the screen. The user had previously been instructed to move the pointer (using the Mouse or Arrow Keys) within the boundary of the selectable region and press the select function key as quickly as possible. Pressing the select function key activated highlighting of another selectable region (these regions appeared in various locations on the screen). The user then moved the pointer to the newly highlighted region and pressed the select function key. Subjects received no indication as to the location of the next selectable region. This process continued until all select function actuations had been made for that trial (after five movements for the first trial). The Home Base Viewport would then highlight and the user was instructed to move the pointer onto the Home Base Viewport and press the selection function key to initiate the next trial. This procedure was repeated for the six trials.

Primary Data Collection Tasks

The primary data collection tasks were the two Movement Tasks and the Experimental Task.

Movement Task I. The Movement Task served as a control for movement time. The function was to determine the time it took to move to a highlighted box and select it. The Movement Task was identical to the Experimental Task with the exception that the boxes representing the Keyboard arrangements did not contain letters. In the Movement Task, boxes were highlighted in a sequence equivalent to the letter position of the word or non-word stimulus to which they were yoked. The user's task was to move to the highlighted box and select it. Once selected, another box was highlighted until the stimulus was "typed."

The Movement Task was comprised of thirty-six trials divided into three blocks of twelve trials each. Each block displayed one Keyboard Arrangement (without letters). The keyboard presentation order for each subject was determined by

a 3 X 3 Latin Square (see Table 1. Study Design), such that on either day each keyboard was used equally in each trial block. There were six stimulus sets (three for the first day and three for the second day), each one containing twelve trials (see Experimental Task procedure for more details on the stimulus sets). Within any given block, the movement patterns associated with one stimulus set were measured by having the subject move the pointer to unlabeled stimulus set locations on the screen. Movement times were obtained by summing the trial times collected within each block.

Table 1. Study Design

	BLOCK 1	BLOCK 2	BLOCK 3
ARROWS:			
Non-Finger 1	K1 SS1	K2 SS2	K3 SS3
Non-Finger 2	K2 SS3	K3 SS1	K1 SS2
Non-Finger 3	K3 SS2	K1 SS3	K2 SS1
Non-Finger 4	K1 SS4	K2 SS5	K3 SS6
Non-Finger 5	K2 SS6	K3 SS4	K1 SS5
Non-Finger 6	K3 SS5	K1 SS6	K2 SS4
MOUSE:			
Non-Finger 7	K1 SS1	K2 SS2	K3 SS3
Non-Finger 8	K2 SS3	K3 SS1	K1 SS2
Non-Finger 9	K3 SS2	K1 SS3	K2 SS1
Non-Finger 10	K1 SS4	K2 SS5	K3 SS6
Non-Finger 11	K2 SS6	K3 SS4	K1 SS5
Non-Finger 12	K3 SS5	K1 SS6	K2 SS4

DAY 1

K= Keyboard
SS = Stimulus Set

Table 1. Study Design (Continued)

MOUSE:	BLOCK 1	BLOCK 2	BLOCK 3
Non-Finger 1	K1 SS4	K2 SS5	K3 SS6
Non-Finger 2	K2 SS6	K3 SS4	K1 SS5
Non-Finger 3	K3 SS5	K1 SS6	K2 SS4
Non-Finger 4	K1 SS1	K2 SS2	K3 SS3
Non-Finger 5	K2 SS3	K3 SS1	K1 SS2
Non-Finger 6	K3 SS2	K1 SS3	K2 SS1
ARROWS:			
Non-Finger 7	K1 SS4	K2 SS5	K3 SS6
Non-Finger 8	K2 SS6	K3 SS4	K1 SS5
Non-Finger 9	K3 SS5	K1 SS6	K2 SS4
Non-Finger 10	K1 SS1	K2 SS2	K3 SS3
Non-Finger 11	K2 SS3	K3 SS1	K1 SS2
Non-Finger 12	K3 SS2	K1 SS3	K2 SS1

K= Keyboard
SS = Stimulus Set

DAY 2

Table 1. Study Design (Continued)

ARROWS:	BLOCK 1	BLOCK 2	BLOCK 3
Finger 13	K1 SS1	K2 SS2	K3 SS3
Finger 14	K2 SS3	K3 SS1	K1 SS2
Finger 15	K3 SS2	K1 SS3	K2 SS1
Finger 16	K1 SS4	K2 SS5	K3 SS6
Finger 17	K2 SS6	K3 SS4	K1 SS5
Finger 18	K3 SS5	K1 SS6	K2 SS4
MOUSE:			
Finger 19	K1 SS1	K2 SS2	K3 SS3
Finger 20	K2 SS3	K3 SS1	K1 SS2
Finger 21	K3 SS2	K1 SS3	K2 SS1
Finger 22	K1 SS4	K2 SS5	K3 SS6
Finger 23	K2 SS6	K3 SS4	K1 SS5
Finger 24	K3 SS5	K1 SS6	K2 SS4

K= Keyboard
SS = Stimulus Set

DAY 1

Table 1. Study Design (Continued)

MOUSE:	BLOCK 1	BLOCK 2	BLOCK 3
Finger 13	K1 SS4	K2 SS5	K3 SS6
Finger 14	K2 SS6	K3 SS4	K1 SS5
Finger 15	K3 SS5	K1 SS6	K2 SS4
Finger 16	K1 SS1	K2 SS2	K3 SS3
Finger 17	K2 SS3	K3 SS1	K1 SS2
Finger 18	K3 SS2	K1 SS3	K2 SS1
ARROWS:			
Finger 19	K1 SS4	K2 SS5	K3 SS6
Finger 20	K2 SS6	K3 SS4	K1 SS5
Finger 21	K3 SS5	K1 SS6	K2 SS4
Finger 22	K1 SS1	K2 SS2	K3 SS3
Finger 23	K2 SS3	K3 SS1	K1 SS2
Finger 24	K3 SS2	K1 SS3	K2 SS1

DAY 2

K= Keyboard
SS = Stimulus Set

Within a given block, a trial began when the pointer was positioned on the Home Base Viewport and the user pressed the select function key. A selectable region highlighted on the displayed keyboard. Users were instructed to move the pointer within the boundary of the region and press the select function key as quickly as possible. Pressing the select function key activated highlighting of the next selectable region, at which time the user moved the pointer to that region. This process continued until all select function actuations were made for that trial (i.e., the user had completed typing movements equivalent to the first word or non-word in the stimulus set). Timing of the trial ended when the last region in the trial had been activated (the select function key was pressed down). At that time, the Home Base Viewport highlighted and the user moved the pointer onto the Home Base Viewport and pressed the select function to initiate the next trial. This procedure was repeated for the twelve trials.

Upon completion of the first block, the Keyboard Arrangement and the stimulus set were changed, and the procedure was repeated for the second block. Likewise, when the second block was complete, the third arrangement was displayed and the user repeated the procedure using the third Keyboard Arrangement and the third stimulus set.

Experimental Task. In the Experimental Task, the user typed a given word or non-word utilizing one of the Keyboard Arrangements and Input Devices. When a stimulus appeared on the screen, the user was instructed to type the letters in the appropriate sequence. For each letter, this involved locating the appropriate letter, moving to the box containing that letter, and selecting it (activating the select function key).

The Experimental Task consisted of thirty-six discrete trials divided into three blocks of twelve trials. Keyboard arrangements were displayed in the exact order as in Movement Task I; however, in this task the keyboard selectable regions were labeled (alphabet displayed). The stimulus sets were given in the exact order as in Movement Task I; however, in this task, each stimulus (word or non-word) within the stimulus set was presented in the Display Viewport.

Each stimulus set consisted of six words and six non-words (twelve trials within a stimulus set). The six word trials were matched with their mirror image non-word trials within the same stimulus set. The order of words and non-words were randomly determined for each stimulus set, and the same random order was used for each subject. To control for order effects, a 6 X 6 Latin Square was used for stimulus sets such that over the two days and three blocks, each stimulus set was used equally in each trial block (see Table 1. Study Design). Combining the Latin Square used for the Keyboard arrangements and the Latin Square used for the stimulus sets resulted in a design where each unique combination of Keyboard Arrangement and stimulus set occurred once equally spaced over every six subjects and over the three blocks.

Each trial in the Experimental Task began when the pointer was positioned on the Home Base Viewport and the user pressed the select function key. At that point, one stimulus (a word or non-word) from the stimulus set was presented in the Display Viewport. Users were instructed to type the stimulus presented as quickly as possible, using the Input Device given and the Keyboard Arrangement displayed. Typing was accomplished by moving the pointer within the boundary of the region containing the desired alphabetical character, and pressing the select function key. As the user typed, the corresponding character was displayed in the Input Viewport.

Users were instructed that correction of typing errors was not possible. If typing errors were made, the users were to continue typing the word as if the incorrectly typed letter had been typed correctly. Data were collected for all typing errors made during this task.

When the user finished typing the stimulus, they moved the pointer back to the Home Base Viewport and pressed the select function key to start the next trial. This continued until all twelve trials were complete. Note that the timing of each trial ended when the user activated the last character of the stimulus (e.g., the last character in the word).

Rating Tasks. Upon finishing each block in the Experimental Task, a Block Questionnaire was administered to the subject. While the questionnaire was being completed, the Keyboard Arrangement and the stimulus set were changed. The subject then proceeded with the second block in the Experimental Task. Following completion of the second block, another Block Questionnaire was administered, the Keyboard and stimulus set were changed, then the third block was presented. A Block Questionnaire was also given upon completion of the third block.

Movement Task II. The second Movement Task, performed upon completion of the Experimental Task and subsequent Subjective Evaluations, was identical to the first Movement Task (Movement Task I). Movement Task II was included to control for practice effects. The procedure for this task is identical to the description for Movement Task I given above.

Day 2 and Rank Order Task. On the second day, the same set of procedures was followed for each subject. Differences were confined to use of the alternative Input Device and the three remaining stimulus sets. At the conclusion of the study, users were asked to rank order their preference using the six conditions formed from the factorial combination of Keyboard Arrangement and Input Device.

RESULTS

With the exception of the Movement Task II, results are presented in the same procedural sequence that was used for the study. First, results from the hard keyboard task (given to subjects prior to performing any on-screen keyboard tasks) are presented. Next, Movement Tasks I and II results are provided; the second Movement Task results are inserted here to make comparisons between the two Movement Tasks. Results for the Experimental Task results are divided into two subsections: the unadjusted results and the adjusted results. Unadjusted results are the raw data obtained from this task; whereas, adjusted results are presented with Movement Task times statistically removed from the Experimental Task times. Finally, subjective scale results are provided.

In the present study, 3 by 2 by 2 by 2 mixed factorial ANOVA's were performed on Movement and Experimental Typing Task data. When significant interactions were found, simple effects analyses were performed to determine locus of significance. All analyses were performed on both input times and number of stimuli typed correctly. With regard to number of stimuli typed correctly, there was only one significant effect-- Stimulus Type. Data concerning stimuli typed correctly for the on-screen tasks are provided when present; however, most data presentation focuses on significant effects found in input time responses. Appendix I includes all ANOVA Summary Tables for objective evaluations.

Hard Keyboard Typing Task

Analysis of the hard keyboard typing test confirmed that finger placement typists typed more words per minute (gross words per minute) than did the non-finger placement typists ($F(1,22) = 13.44$, $p = .001$); and finger placement typists typed more words correctly (number of stimuli typed correctly) than did the non-finger placement typists ($F(1,22) = 5.42$, $p = .03$). See Appendix K for all means and standard deviations.

Movement Tasks

Movement Task I

For the first Movement Task, analysis of total input times revealed significant effects for Stimulus Type ($F(1,22) = 7.02$, $p = .015$), Input Device ($F(1,22) = 582.65$, $p < .001$), Keyboard ($F(2,44) = 4.71$, $p = .024$), and Input Device by Keyboard ($F(2,44) = 11.75$, $p < .001$).

Although there were significant differences between words versus non-words (Stimulus Type) in a task in which the stimuli were not presented, the difference

between the means was 0.1 second. Non-words ($\underline{M}$ = 10.67) took less time to input than words ($\underline{M}$ = 10.77).

It took longer to input the stimuli via the Arrow Keys than the Mouse for all three Keyboard Arrangements (see Figure 3). Analysis of simple comparisons for the Input Device by Keyboard effect showed that for the Mouse condition the 1-Row arrangement took more time to input than the QWERTY ($\underline{F}(1,22) = 73.02$, $\underline{p} < .001$) or 3-Row ($\underline{F}(1,22) = 83.68$, $\underline{p} < .001$) arrangements. However, significant differences in input times for the Arrow Keys conditions were not found.

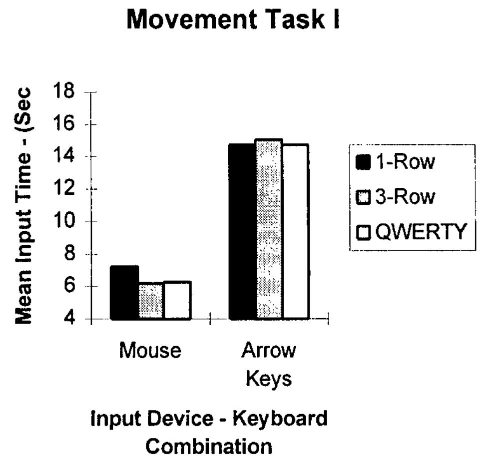

Figure 3. Mean input time as a function of Keyboard Arrangement and Input Device for Movement Task I

Movement Task II

For the second Movement Task, analysis of total input times also revealed significant effects for Stimulus Type ($\underline{F}(1,22) = 4.36$, $\underline{p} = .049$), Input Device ($\underline{F}(1,22) = 512.01$, $\underline{p} < .001$), Keyboard ($\underline{F}(2,44) = 12.66$, $\underline{p} < .001$), and Input Device by Keyboard ($\underline{F}(2,44) = 4.06$, $\underline{p} = .026$). In addition to these effects, one additional effect not present in Movement Task I results was found. This was the interaction of Typing Method and Stimulus Type ($\underline{F}(1,22) = 4.69$, $\underline{p} < .042$) for Movement Task II.

Analysis of the interaction of Typing Method and Stimulus Type showed that finger placement typists took more time to type words ($\underline{M}$ = 9.66) than non-words ($\underline{M}$ = 9.45)-- a difference of .21 seconds ($\underline{F}(1,22) = 9.04$, $\underline{p} = .006$) (see Figure 4). For non-finger placement typists, significant differences in input times for Stimulus Type were not found ($\underline{F}(1,22) = .00$, $\underline{p} < .957$.).

Movement Task II

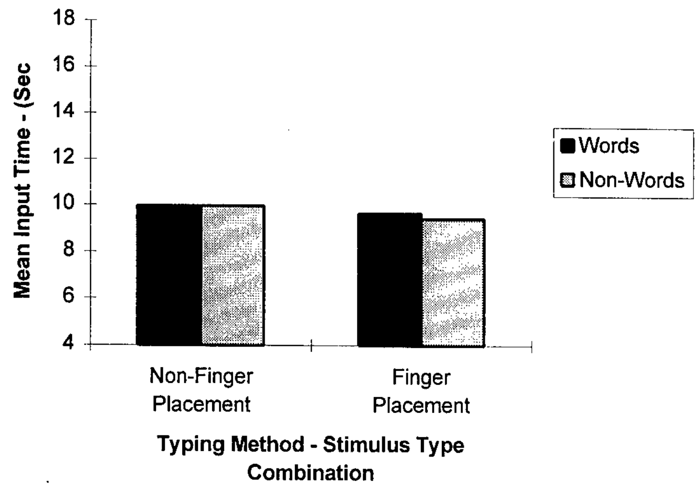

Figure 4. Mean input time as a function of Typing Method and Stimulus Type for Movement Task II

As in Movement Task I, it took longer to input the stimuli via the Arrow Keys than the Mouse for all three Keyboard Arrangements in Movement Task II (see Figure 5). Analysis of simple comparisons for the Input Device by Keyboard interaction showed that for the Mouse condition, the 3-Row and QWERTY arrangements resulted in faster times than the 1-Row arrangement ($\underline{F}(1,22) = 55.18$, $\underline{p} < .001$ and $\underline{F}(1,22) = 53.25$, $\underline{p} < .001$ respectively). However, there were no significant differences in input times for the Arrow Keys conditions.

Average of Two Movement Tasks

Although the times for second Movement Task ($\underline{M} = 9.77$) were faster than times for first Movement Task ($\underline{M} = 10.72$), the movement times for the two tasks were significantly correlated ($\underline{r}$'s ranged from 0.7422 to 0.9303) (see Table 2). In addition to the high correlation between these tasks, analyses of variance (including simple comparisons) performed on the two Movement Tasks revealed the same pattern of results and significance, with the exception of the Typing Method by Stimulus Type interaction.

Movement Task II

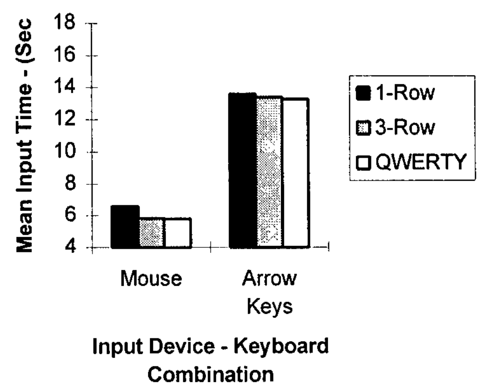

Figure 5. Mean input time as a function of Keyboard Arrangement and Input Device for Movement Task II

Table 2. Correlations between Movement Task I and II

Conditions	Movement Tasks I and II
Words, Mouse, 1-Row	.8742
Words, Mouse, 3-Row	.8289
Words, Mouse, QWERTY	.7422
Words, Arrow Keys, 1-Row	.9026
Words, Arrow Keys, 3-Row	.9303
Words, Arrow Keys, QWERTY	.9175
Non-Words, Mouse, 1-Row	.8143
Non-Words, Mouse, 3-Row	.8024
Non-Words, Mouse, QWERTY	.8535
Non-Words, Arrow Keys, 1-Row	.9245
Non-Words, Arrow Keys, 3-Row	.8753
Non-Words, Arrow Keys, QWERTY	.9014

Due to the high correlation between the two Movement Tasks and the similarities between the significant effects in the two Movement Tasks, the decision was made to use the average times for the first and second Movement Tasks as a covariate in the analysis of typing time.

Results from averaging the two Movement Tasks revealed the same significant effects as those found in Movement Task I alone (i.e., the effect of Typing Method by Stimulus Type was no longer significant). The averaged effects showed significant differences for Stimulus Type ($\underline{F}(1,22) = 9.86$, $\underline{p} = .005$), Input Device ($\underline{F}(1,22) = 565.02$, $\underline{p} < .001$), Keyboard ($\underline{F}(2,44) = 9.82$, $\underline{p} = .001$), and Input Device by Keyboard ($\underline{F}(2,44) = 9.46$, $\underline{p} < .001$). Moreover, the pattern of results for the averaged tasks was the same as the pattern of the two tasks taken independently.

Experimental Typing Task

Unadjusted

Analysis of total input times for the On-Screen Experimental Task revealed significant effects for Stimulus Type ($F(1,22) = 10.13$, $p = .004$), Input Device ($F(1,22) = 474.20$, $p < .001$), Keyboard ($F(2,44) = 8.31$, $p = .001$), and Input Device by Keyboard ($F(2,44) = 9.76$, $p < .001$). As expected, non-words ($M = 12.98$) took longer to input than words ($M = 12.38$). In contrast with input time, analysis of errors for the Experimental Task revealed only a significant effect for Stimulus Type ($F(1,22) = 10.02$, $p = .004$). Under this condition, more words were typed correctly ($M = 5.81$) than non-words ($M = 5.6$).

The largest differences in input time were a function of Input Device; it took much longer to input the stimuli via the Arrow Keys than the Mouse for all three Keyboard Arrangements (see Figure 6). Analysis of simple comparisons for the Input Device by Keyboard interaction showed that for the Mouse condition the QWERTY keyboard was significantly faster than either the 1-Row ($F(1,22) = 64.82$, $p < .001$) or 3-Row arrangements ($F(1,22) = 37.32$, $p < .001$), with the latter two not differing significantly from one another ($F(1,22) = 0.38$, $p = .546$). For the Arrow Keys, the QWERTY and the 1-Row did not differ significantly from each other ($F(1,22) = 0.52$, $p = .477$); however, they were both significantly faster than the 3-Row arrangement ($F(1,22) = 6.08$, $p = .022$), and $F(1,22) = 7.51$, $p = .012$ for the QWERTY and 1-Row comparisons respectively).

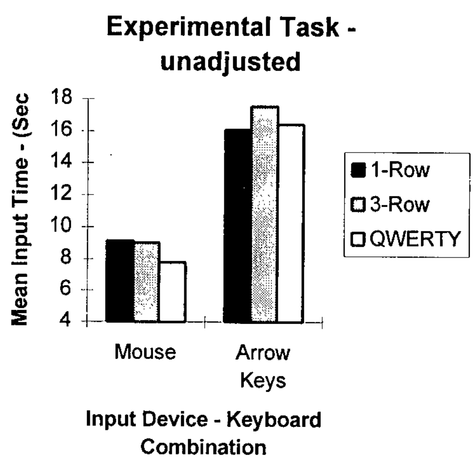

Figure 6. Mean input time as a function of Keyboard Arrangement and Input Device for Experimental Task unadjusted

Adjusted

Since the results of the Experimental Task could simply be due to movement time, an analysis of covariance was performed to remove the effect of movement time.

The results of the covariance analysis (statistically removing the effects of movement time from the Experimental Task) were different than the unadjusted

results in two ways. First, the effect of Input Device was no longer significant ($\underline{F}(1,21) = .88$, $\underline{p} = .359$). Second, there was no longer an interaction between Input Device and Keyboard Arrangement ($\underline{F}(2, 43) = 3.16$, $\underline{p} = .053$). Figure 7 identifies the adjusted means of Input Device and Keyboard after removing the effect of movement time (Note that the interaction was no longer present). Most of the variability due to Input Device had been removed by controlling movement time.

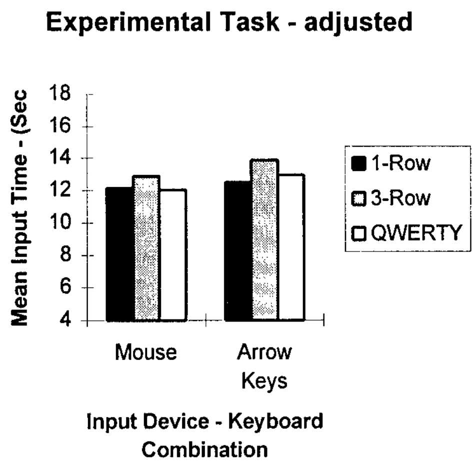

Figure 7. Mean input time as a function of Keyboard Arrangement and Input Device for Experimental Task adjusted

There were two significant effects for the adjusted times. First, it took longer to type non-words than words ($\underline{F}(1,22) = 7.02$, $\underline{p} = .015$). Second, there was an effect of keyboard arrangements ($\underline{F}(2,44) = 4.71$, $\underline{p} = .024$).

Analysis of the main effect of Keyboard revealed that the QWERTY and the 1-Row did not differ significantly from each other ($\underline{F}(1,21) = .14$, $\underline{p} = .716$); however, they were both significantly faster than the 3-Row arrangement ($\underline{F}(1,21) = 14.73$, $\underline{p} = .001$), and $\underline{F}(1,21) = 17.88$, $\underline{p} < .001$ for the QWERTY and 1-Row comparisons respectively).

Subjective Scales

Two scales were used to obtain subjective data. The first scale provided results concerning ease of use of the various block conditions (e.g., Mouse with the QWERTY keyboard typing words). The second scale provided rankings of the six pairings of display concepts (e.g., Mouse with QWERTY vs. Mouse with 1-Row). The rank order scale was given at the end of the test.

Rating Scale

The ratings scale (the Block Questionnaire) was given at the end of each block. Reverse polarity was used throughout the questionnaire to minimize biases toward rating responses. In the analysis, two statements (Statement 1 typing of non-words and Statement 2 typing of words) revealed all of the effects found in the remaining seven statements (3 through 9). The additional seven statements were redundant.

Analysis of subjective ratings for Statement 1 revealed significant effects on typing of non-words for Typing Method ($F(1,20) = 7.60$, $p = .012$), Input Device ($F(1,20) = 5.44$, $p = .030$), and Input Device by Keyboard ($F(2,40) = 8.59$, $p = .001$). Finger placement typists rated the ease of typing non-words higher than non-finger placement typists. The interaction of Input Device and Keyboard Arrangement (see Figure 8) showed that for the Arrow Keys, subjects rated the 1-Row Alphabetical arrangement easier to use to type non-words than either the 3-Row ($F(1,20) = 19.59$, $p < .001$) or the QWERTY ($F(1,20) = 13.87$, $p = .001$), with the latter two not differing significantly from one another ($F(1,20) = 0.07$, $p = .797$). For the Mouse conditions, there were no significant differences in the ease of typing non-words.

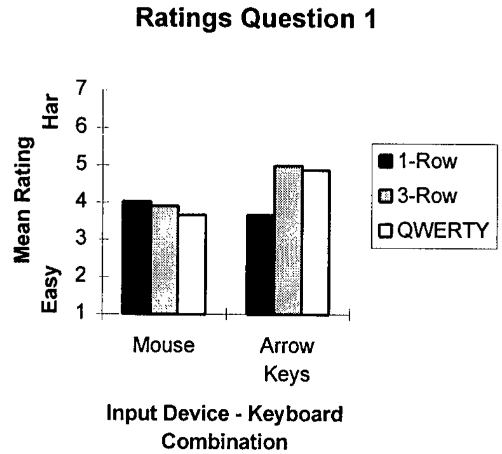

Figure 8. Subjective ratings as a function of Keyboard Arrangement and Input Device for typing of non-words (Statement 1)

Analysis of ratings for Statement 2 (ease-of-use in typing words) revealed only the Input Device by Keyboard interaction to be significant ($F(2,40) = 3.70$, $p = .033$). For words, there were no significant differences between finger placement typist and non-finger placement typist ratings ($F(1,20) = .00$, $p = .990$). The pattern of results for the interaction of Input Device and Keyboard Arrangement for Statement 2 was the same as in Statement 1 (see Figure 9). For the Arrow Keys, subjects rated the 1-Row Alphabetical arrangement easier to type words than either the 3-Row ($F(1,20) = 6.77$, $p = .017$) or the QWERTY ($F(1,20) = 10.13$, $p = .005$), with the latter two not differing significantly from one another ($F(1,20) = .71$, $p = .408$). For the Mouse, subjects ratings for the three arrangements did not differ significantly from one another ($F(1,20) = 0.06$, $p = .805$).

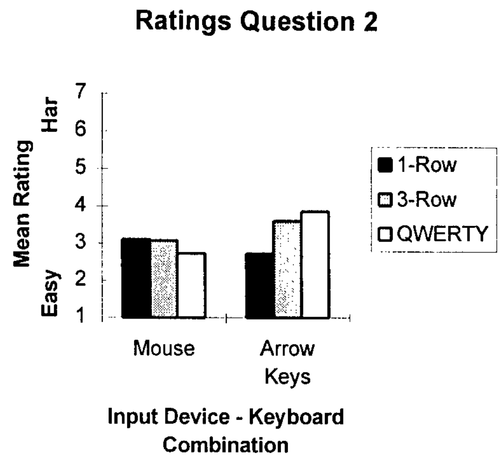

Figure 9. Subjective ratings as a function of Keyboard Arrangement and Input Device for typing of words (Statement 2)

Ranking Scale

For the ranking scale, a Friedman 1-Way ANOVA revealed a difference in rankings overall (Chi Square(5) = 93.24, $p < .001$). Overall, the Arrow Key with the 3-Row arrangement was least preferred, and the Mouse with the QWERTY arrangement was the most preferred (see Figure 10). Pair-wise comparisons revealed that for the Mouse, the QWERTY keyboard was preferred to the other arrangements (Chi Square(1) = 24.00, $p < .001$ and Chi Square(1) = 24.00, $p < .001$ for the 1-Row and 3-Row comparisons, respectively); however, there was not a significant difference in ranking between the two alphabetical arrangements (Chi Square(1) = 0.17, $p = .683$). Rankings for Arrow Key pair-wise conditions showed significant differences among the three arrangements with the rank order of preference from most preferred to least preferred being QWERTY, 1-Row, and 3-Row (Chi Square(1) = 24.00, $p < .001$ for the QWERTY vs. 1-Row comparison, Chi Square(1) = 24.00, $p < .001$ for the QWERTY vs. 3-Row comparison, and Chi Square(1) = 6.00, $p = .014$ for the 1-Row vs. 3-Row comparison).

Subjective Rankings

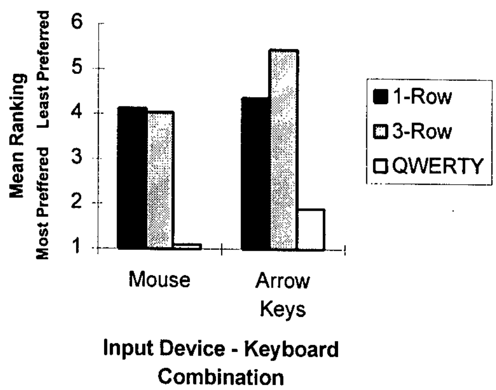

Figure 10. Subjective rankings as a function of Keyboard Arrangement and Input Device

DISCUSSION

The major result of this study was an interaction of Keyboard and Input Device for the performance measures on the Experimental Task, the ease-of-use ratings, and the preference rankings. For the Arrow Key condition, the 1-Row and QWERTY arrangements resulted in faster input times than the 3-Row arrangement. However, for the Mouse condition, input times for the QWERTY arrangement were faster than either the 1-Row or 3-Row arrangements. When movement time was controlled (Experimental Task adjusted), input times for the QWERTY and 1-Row were faster than the 3-Row for both the Arrow Key and Mouse conditions.

Performance differences before and after removal of movement time clearly show that the 1-Row was slower than the QWERTY arrangement for Mouse condition simply due to movement time. Once movement time was controlled, the interaction of Input Device with Keyboard was no longer significant. This effect of movement time on the Mouse Input Device could be due to inefficient movement control when using the Mouse with the 1-Row arrangement. The 1-Row arrangement necessitates movement mostly along the horizontal axis, and yet the Mouse Input Device permits movement in both the horizontal and vertical planes, leading to unnecessary movement error (overshooting the target in the vertical plane). This suggests that designs which limit vertical movement of the indirect input device would potentially provide better movement time results with the 1-Row Alphabetical Keyboard arrangement.

With movement time controlled, the QWERTY and 1-Row arrangements resulted in faster input times than the 3-Row arrangement. The faster input times for the 1-Row are due to the notion of Norman & Fisher (1982) that people visualize the alphabet in a linear fashion. These cognitive time differences between the 1-Row and 3-Row arrangements show that the 1-Row arrangement was more compatible with how people perceive the alphabet.

Inclusion of the 3-Row Alphabetical arrangement did provide insight as to whether it was the number of rows (1 versus 3) or the arrangement of the letters (alphabetical versus QWERTY) which made a difference in performance. Controlling for compactness of arrangements was accomplished by controlling movement time. With movement time statistically removed, the 1-Row was still faster than the 3-Row arrangement. Again, this interpretation is consistent with potential compatibility problem between the mental computations required for visualizing positioning of letters in the alphabet and then physically locating the letter on 3-row alphabetical arrangements (Norman & Fisher, 1982). Norman & Fisher thought that the cognitive time required to perform the task when using the 3-row Alphabetical arrangements would be slow, which is consistent with the findings of the present study.

Performance advantages of the QWERTY arrangement cannot be attributed simply to compactness of the 3-Row arrangement. The QWERTY and the 3-Row arrangements were equivalent in compactness; therefore, if movement time was the only consideration, one would expect no differences between these arrangements. However, whether or not movement time was controlled, the QWERTY was still faster than the 3-Row. The primary cognitive difference between the 3-Row and QWERTY arrangements is probably due to the fact that users are familiar with the QWERTY arrangement. Users of all types experience the QWERTY arrangement on a regular basis; therefore, task performance improves when this arrangement is used.

Measurement of ease-of-use for the Mouse condition showed that the 1-Row, 3-Row, and QWERTY arrangements were equivalent. This occurred despite the fact that the QWERTY resulted in faster input times than the other two arrangements. This difference in findings could be due to the nature of the on-screen task as being primarily a pointing task, not a typing task. As argued by Card, English, and Burr (1978), the Mouse is the most effective indirect Input Device when used in a pointing task. The effectiveness of the Mouse in the pointing task could have resulted in rapid and effortless performance in the present study, therefore not affecting subjective judgments of the ease of the task when using the Mouse.

For the Arrow Keys, subjects rated the 1-Row arrangement as being easier to use than either the QWERTY or 3-Row arrangements. Interestingly, the mean ease-of-use rating for the Arrow Keys with 1-Row condition was similar to the ratings for the three Mouse conditions. This is despite the fact that it took longer to input stimuli with the Arrow Keys than with the Mouse. This finding could be due to the efficiency of movement control between the Arrow Keys and 1-Row arrangement. In this situation, after users had positioned the pointer onto the alphabetical row, movement was only required in the horizontal plane, therefore making inputs seem much easier.

Measurement of preference rankings showed that overall, for both the Mouse and Arrow Keys conditions, the QWERTY arrangement was most preferred. This occurred despite the fact that all keyboard conditions were equally easy to use with the Mouse, and that subjects rated the 1-Row as easier to use with the Arrow Keys. There are three possible factors which may have contributed to these discrepant results. First, preference was a forced choice measure; whereas, ease-of-use was not.

This factor could explain the Mouse results, but not the reversal for the 1-Row versus QWERTY comparison for the Arrow Key condition. Second, there are qualitative differences between the constructs of ease-of-use and preference measures; therefore, the same results should not be expected between these two measures. The final factor is the time at which subjective judgments were made. Ease-of-use ratings were made at the end of each trial; whereas, preferences were made at the end of the study. As a result, ease-of-use may have been more closely tied to the performance of the immediately proceeding task. Preference judgments, on the other hand, were more retrospective; therefore, subjects may have taken time to reflect on and compare their performance under the different conditions. In any case, the QWERTY arrangement was the most preferred. The most parsimonious explanation is that since subjects were most familiar with the QWERTY arrangement, they preferred it the most.

Other Findings

Analysis of the further findings in the present study reveals that tasks which included movement time (Movement and Experimental unadjusted times) showed Input Device effects to be significant-- the Mouse resulted in much faster input times than the Arrow Keys. This difference can be attributed to movement time since the device effect was removed when movement time was controlled. As stated earlier in the Discussion Section, this result has been well documented in previous literature pertaining to on-screen manipulations (Card, English, & Burr, 1978). In their study, Card, English, and Burr found that, for pointing tasks, the mouse was the most efficient means of indirect pointing, while the keypad was the least efficient. The combined findings of the present study with those of Card, English, and Burr are consistent with the recommendation that, for on-screen pointing tasks, designers should utilize the Mouse over Arrow Keys when using indirect pointing devices.

As expected, the present study shows that designers cannot extrapolate all results from hard keyboard studies to on-screen keyboard designs. Observable differences between the nature of the hard keyboard and on-screen keyboard tasks indicate that the hard keyboard task is visual only for hunt-and-peck or non-finger placement typists; whereas, the on-screen keyboard task is visual for all typing skill levels. This is probably due to the notion that the on-screen task is a pointing task, not simply a typing task.

The failure of Typing Method to interact with the other independent variables for typing task times reinforces the notion that findings from hard keyboard studies should not be extrapolated to on-screen keyboard designs. Previous research on hard keyboards (Michaels, 1971) has shown performance differences among Keyboard Arrangements as a function of skill, yet Keyboard Arrangement and skill (Typing Method) did not interact in the present study for typing task times. It might be argued, however, that Typing Method is not the same as typing skill, and therefore the same effects should not be expected. However, this argument is somewhat mitigated, because it was shown that finger placement typists typed more gross words per minute and made fewer errors than non-finger placement typists. Thus, Typing Method is highly correlated with skill. The failure to find an interaction with Typing

Method probably represents the fact that the on-screen task is a pointing task, not a pure typing task.

Overall analysis of number of stimuli typed correctly revealed that Stimulus Type was the only variable sensitive to the measure. Words were typed more accurately than non-words in the Experimental Task. This finding could be due to the notion that words were perceived as a chunk (therefore making correct spelling easier to accommodate), while non-words were perceived as individual letters (thereby making correct spelling more prone to errors).

Potential future research topics include several variations on the design and methodology used in the present study. One potential variation could include the use of subjects chosen from a subject pool other than "undergraduate college students." Subjects used in the present study were all undergraduate college students who were at least somewhat familiar with the QWERTY keyboard. This constraint could have an effect on the generalizability of this study's results to user populations less familiar with the QWERTY arrangement. Another variation could include use of other indirect input devices such as a joystick or trackball. For applications such as portable maintenance aids, the joystick or trackball provide more portability than the mouse. Therefore, evaluation of keyboard arrangements with these input devices might be worthwhile. The effectiveness of movement control when using the joystick or trackball with the 1-Row arrangement would be of primary interest in this type of study. Finally, a study including the effect of extensive training on the overall task could result in differences in both performance and subjective evaluation results for the three keyboard arrangements.

BIBLIOGRAPHY

Alden, D.G., Daniels, R.W. & Kanarick, A.F. (1972). Keyboard design and operations: A review of the major issues. *Human Factors*, *14*(4), 275-293.

Amell, J.R., Ewry, M.E., & Colle, H.A. (1988). Next generation keyboards: The importance of cognitive compatibility. *Second Annual Workshop on Space Operations Automation and Robotics* (SOAR '88), 233-236.

Boff, K. & Lincoln, J.E. (1988). *Engineering data compendium: Human perception and performance*. WPAFB, OH: AAMRL/HE.

Card, S.K., English, W.K., & Burr, B.J. (1978). Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics*, *21*(8), 601-613.

Carr, T.H., Posner, M.I., Pollatsek, A., & Snyder, C.R.R. (1979). Orthography and familiarity effects in word processing. *Journal of Experimental Psychology: General*, *108*(4), 389-414.

English, W.K., Engelbart, D.C., & Berman, M.L. (1967). Display-selection techniques for text manipulation. *IEEE Transactions on Human Factors in Electronics*, *HFE-8*(1), 5-15.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*(6), 381-391.

Fitts, P.M., & Peterson, J.R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology*, *67*(2), 103-112.

Gibson, E.J., Pick, A., Osser, H., & Hammond, M. (1962). The role of grapheme-phoneme correspondence in the perception of words. *American Journal of Psychology*, *75*, 554-570.

Goodman, D. & Dickinson, J. (1983). Human factors in keypad design. In *Proceedings of the Human Factors Society - 27th Annual Meeting*, (pp. 191-193). Santa Monica, CA: Human Factors Society.

Goodman, D., & Dickinson, J. (1985). Human factors design considerations for public videotex input devices. *Behaviour and Information Technology*, *4*(3), 189-200.

Goodwin, N.C. (1975). Cursor positioning on an electronic display using lightpen, lightgun, or keyboard for three basic tasks. *Human Factors*, *17*(3), 289-295.

Gould, J.D., Greene, S.L., Boies, S.J., Meluson, A., & Rasamny M. (1990). Using a touchscreen for simple tasks. *Interacting with Computers*, *2*(1), 59-74.

Greenstein, J.S., & Arnaut, L.Y. (1988). Human factors aspects of manual computer input devices. In M. Helander (Ed.) *Handbook of Human-Computer Interaction.* (pp. 495- 519). Amsterdam: North-Holland.

Hamilton, J.M.E., & Sanford, A.J. (1978). The symbolic distance effect for alphabetic order judgements: A subjective report and reaction time analysis. *Quarterly Journal of Experimental Psychology*, *30*, 33-43.

Hirsch, R.S. (1970). Effects of standard versus alphabetical keyboard formats on typing performance. *Journal of Applied Psychology*, *54*(6), 484-490.

Howell, W.C., & Kreidler, D.L. (1963). Information processing under contradictory instructional sets. *Journal of Experimental Psychology*, *65*(1), 39-46.

Ilg, R. (1987). Ergonomic keyboard design. *Behaviour and Information Technology*, *6*(3), 303-309.

Karat, J., McDonald, & Anderson, M. (1986). A comparison of selection techniques: Touch panel, mouse and keyboard. *Journal Man-Machine Studies*, *25*, 73-88.

Kinkead, R. (1975). Typing speed, keying rates, and optimal keyboard layouts. In *Proceedings of the Human Factors Society - 19th Annual Meeting*, (pp. 159-161). Santa Monica, CA: Human Factors Society.

Klemmer, E.T. & Lockhead, G.R. (1962). Productivity and errors in two keying tasks: A field study. *Journal of Applied Psychology*, *46*(6), 401-408.

Kroemer, E.K.H. (1972). Human engineering the keyboard. *Human Factors*, *14*(1), 51-63.

Marmaras, N., & Lyritzis, K. (1990). Keyboard layout for occasional users. In D. Diaper et al. (Eds.) *Human-computer Interaction - Interact '90* (pp. 707-712). Amsterdam: North-Holland.

Martin, G.L. (1988). Configuring a numeric keypad for a touch screen. *Ergonomics*, *31*(6), 945-953.

Meister, D. (1986). Human Factors Testing and Evaluation. In G. Salvendy (Ed.) *Advances in Human Factors/Ergonomics* (Series 5). Amsterdam: Elsevier.

Michaels, S.E. (1971). Qwerty versus alphabetic keyboards as a function of typing skill. *Human Factors*, *13*(5), 419-426.

Myers, B.A. (1990). A new model for handling input. *ACM Transactions on Information Systems*, *8*(3), 289-320.

Nakaseko, M., Grandjean, E., Hunting, W., & Gierer, R. (1985). Studies on ergonomically designed alphanumeric keyboards. *Human Factors*, *27*(2), 175-187.

Norman, D.A., & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. *Human Factors*, *24*(5), 509-519.

Pachella, R. (1974). The use of reaction time measures in information processing research. In B.H. Kantowitz (Ed.) *Human Information Processing*. Hillsdale, N.J.: Lawrence Erlbaum.

Potosnak, K.M. (1988). Keys and keyboards. In M. Helander (Ed.) *Handbook of Human-Computer Interaction* (pp. 475-519). Amsterdam: North-Holland.

Salthouse, T.A. (1986). Perceptual, cognitive, and motoric aspects of transcription typing. *Psychological Bulletin*, *99*(3), 303-319.

Salvendy, G. (1987). *Handbook of Human Factors*. New York: John Wiley & Sons.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W.G. Koster (Ed.) *Acta Psychologica 30 Attention and Performance II* (pp. 276-315). Amsterdam: North-Holland.

Thomas, D.L., & Clay, J.D. (1988). *Computer-based maintenance aids for technicians: Project final report* (Report No. AFHRL-TR-87-44). Brooks AFB, TX: Air Force Human Resources Laboratory (HQ AFHRL).

Welford, A.T. (1968). *Fundamentals of Skill*. London: Butler and Tanner Ltd.

Williams, J.R., & Leaf, W.A. (1986). Subjective and objective judgments of screen formats. In *Proceedings of the Human Factors Society - 30th Annual Meeting*, (pp. 689-693). Santa Monica, CA: Human Factors Society.

APPENDIX A: BIOGRAPHICAL DATA

BIOGRAPHICAL DATA

Subject Name: Subject #:

Gender: M F

Age:

Handedness: Left Right

College Year: Freshman Sophomore Junior Senior

Demographics (Home State):

APPENDIX B: SIGN-UP SHEETS

SIGN-UP SHEETS

NAME OF EXPERIMENTER: Laurie Quill

SEMESTER: Fall 1992 CREDIT HOURS: 2

RESTRICTIONS: Sign-up only if you answer YES to the statements below:

- You must be right handed.
- You rarely, if ever, look at the alphabetical keys when typing (looking at the number keys does not matter).
- While alternating among your ten fingers, each time you type a letter, you use the same finger to type it.

To volunteer, fill in your name and local phone number. Please copy all relevant information and be prompt. If your are unable to attend, please phone the experimenter and cancel your appointment (leave a message on the answering machine if the experimenter is not available).

NAME OF EXPERIMENT: On-Screen

NAME OF EXPERIMENTER: Laurie Quill

SEMESTER: Fall 1992 CREDIT HOURS: 2

RESTRICTIONS: Sign-up only if you answer YES to both of the statements below:

- You must be right handed.

- You frequently look at the keys before moving a finger on the key to type a letter.

- For some keys, you may use one finger to type the key one time and another finger to type the same key another time.

To volunteer, fill in your name and local phone number. Please copy all relevant information and be prompt. If your are unable to attend, please phone the experimenter and cancel your appointment (leave a message on the answering machine if the experimenter is not available).

APPENDIX C: TYPING INSTRUCTIONS AND TEST

TYPING INSTRUCTIONS AND TEST

Instructions:

1. Take up to three 2-minute timings. Repeat the text if you finish before the end of 2 minutes.

2. Attempt to get at least one score within 5 errors.

Test:

The choice of a career is not an easy matter. Tests cannot give a positive answer concerning the career you should choose. You are too complex for accurate and complete analysis. A test that shows you are capable of doing a certain type of work is no proof that you will be happy doing it. For the choice of a career depends on a variety of factors.

The most important factors are your likes and dislikes. So it seems you have to choose your own career. No one can make the choice for you. Your need for ready money might force you to accept the first job offered. Such necessity should not kill your drive to seek the kind of job you are set on. You can still climb your way, little by little, to that job. Make sure your choice is an intelligent one. Then equip yourself for that sort of career.

APPENDIX D: CRITERIA FOR TYPING METHOD

CRITERIA FOR TYPING METHOD

If the answer to question 1 is yes, the typist is a finger placement typist. Answers to questions 2 and 3 also assist in identifying finger placement categorization, and question 4 will assist in identifying a non-finger placement typist. All four of these criteria will be used; however, the primary criteria will be the first one.

1. While typing the text, most of the time the eyes are focused on the text to be typed or the text typed (as opposed to switching between the hard keys and the text to be typed or the text typed). For example, the head does not move down to observe the hard keys very often.

2. Upon preparing to type, the two index fingers are placed on the "F" and "J" keys.

3. Upon preparing to type, the third, fourth and fifth fingers on both the right and left hands are placed on the Home Row on consecutive keys extending from the index fingers.

4. Typing only begins after several words have been read and the head moves down to look at the hard keys.

APPENDIX E: STIMULUS SETS

STIMULUS SETS

1. Words: FOXY, BROWN, QUICK, JUMPED, SHOVEL, GAZETTE

   Non-words: YXOF, NWORB, KCIUQ, DEPMUJ, LEVOHS, ETTEZAG

2. Words: QUIZ, FIGHT, PROXY, BLEEDS, WICKED, JIVEMAN

   Non-words: ZIUQ, THGIF, YXORP, SDEELB, DEKCIW, NAMEVIJ

3. Words: FIBS, VAMPS, WAXED, HOCKEY, QUARTZ, JINGLES

   Non-words: SBIF, SPMAV, DEXAW, YEKCOH, ZTRAUQ, SELGNIJ

4. Words: JINX, ZEBRA, WIMPY, QUIVER, FLIGHT, DOCKETS

   Non-words: XNIJ, ARBEZ, YPMIW, REVIUQ, THGILF, STEKCOD

5. Words: JAMB, RITZY, VEXED, SQUAWK, PLIGHT, CONFERS

   Non-words: BMAJ, YZTIR, DEXEV, KWAUQS, THGILP, SREFNOC

6. Words: QUAY, WHARF, VICKS, JUDGES, ZOMBIE, EXPLANT

   Non-words: YAUQ, FRAHW, SKCIV, SEGDUJ, EIBMOZ, TNALPXE

STIMULUS SETS
(Randomized)

1. SHOVEL, QUICK, YXOF, BROWN, ETTEZAG, KCIUQ, DEPMUJ, LEVOHS, NWORB, JUMPED, GAZETTE, FOXY

2. JIVEMAN, YXORP, WICKED, BLEEDS, NAMEVIJ, THGIF, ZIUQ, FIGHT, PROXY, SDEELB, QUIZ, DEKCIW

3. ZTRAUQ, HOCKEY, SBIF, JINGLES, VAMPS, DEXAW, SELGNIJ, YEKCOH, SPMAV, QUARTZ, WAXED, FIBS

4. JINX, STEKCOD, ARBEZ, QUIVER, DOCKETS, THGILF, XNIJ, YPMIW, ZEBRA, WIMPY, REVIUQ, FLIGHT

5. JAMB, VEXED, KWAUQS, YZTIR, SREFNOC, SQUAWK, THGILP, CONFERS, DEXEV, BMAJ, RITZY, PLIGHT

6. QUAY, FRAHW, SKCIV, YAUQ, JUDGES, ZOMBIE, EXPLANT, EIBMOZ, TNALPXE, WHARF, VICKS, SEGDUJ

APPENDIX F: BLOCK QUESTIONNAIRE

BLOCK QUESTIONNAIRE

Circle the number which best reflects your opinion with respect to the following statements. **NOTE: HARD & EASY and GOOD & BAD alternate positions.**

1. Ease-of-use typing NON-WORDS with this on-screen KEYBOARD ARRANGEMENT, while using this INPUT DEVICE (mouse or arrow keys) was:

   HARD 1 2 3 4 5 6 7 **EASY**

2. Ease-of-use typing WORDS with this on-screen KEYBOARD ARRANGEMENT, while using this INPUT DEVICE (mouse or arrow keys) was:

   EASY 1 2 3 4 5 6 7 **HARD**

3. Ease-of-use with this on-screen KEYBOARD ARRANGEMENT, while using this INPUT DEVICE (mouse or arrow keys) was:

   HARD 1 2 3 4 5 6 7 **EASY**

4. Typing NON-WORDS while using the INPUT DEVICE (mouse or arrow keys) was:

   EASY 1 2 3 4 5 6 7 **HARD**

5. Typing WORDS while using the INPUT DEVICE (mouse or arrow keys) was:

   HARD 1 2 3 4 5 6 7 **EASY**

6. Typing NON-WORDS with this on-screen KEYBOARD ARRANGEMENT was:

EASY 1 2 3 4 5 6 7 **HARD**

7. Typing WORDS with this on-screen KEYBOARD ARRANGEMENT was:

HARD 1 2 3 4 5 6 7 **EASY**

8. Ease-of-use with this on-screen KEYBOARD ARRANGEMENT was:

EASY 1 2 3 4 5 6 7 **HARD**

9. Ease-of-use while using this INPUT DEVICE (mouse or arrow keys) was:

HARD 1 2 3 4 5 6 7 **EASY**

10. DENSITY OF THE LETTERS with this on-screen keyboard arrangement (e.g., how close together they were) was:

BAD 1 2 3 4 5 6 7 **GOOD**

11. SIZE OF THE LETTERS (individual target size) with this on-screen keyboard arrangement was:

GOOD 1 2 3 4 5 6 7 **BAD**

APPENDIX G: RANK ORDER SCALE

TEST QUESTIONNAIRE

Rank order the list below from 1 to 6 according to the statement below (1 being your first choice, 6 being your last choice).

If you had a choice as to the keyboard arrangement and input device to use, you would choose:

_____ Straight alphabetical keyboard arrangement with the arrow keys input device.

_____ 3-Row alphabetical keyboard arrangement with the arrow keys input device.

_____ QWERTY keyboard arrangement with the arrow keys input device.

_____ Straight alphabetical keyboard arrangement with the mouse input device.

_____ 3-Row alphabetical keyboard arrangement with the mouse input device.

_____ QWERTY keyboard arrangement with the mouse input device.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

Straight Alphabetical Keyboard (1-Row)

A	B	C	D	E	F	G	H	I	J
K	L	M	N	O	P	Q	R	S	
T	U	V	W	X	Y	Z			

Three-Row, Horizontal Alphabetical Keyboard (3-Row)

Q	W	E	R	T	Y	U	I	O	P
A	S	D	F	G	H	J	K	L	
Z	X	C	V	B	N	M			

Sholes Keyboard (QWERTY)

1,4,13,16,25,28

APPENDIX H: INSTRUCTIONS

INSTRUCTIONS

This study is divided into two sessions (today and the second day of your participation). You will be performing basically the same tasks on both days. Please use only one hand to perform the task. On either day you will be given five tasks. I will try to explain everything you need to know to perform each of these tasks. Keep in mind that "trials" are timed. You may rest, [reposition the mouse input device on the mouse pad,] etc. between trials and the time will NOT be recorded. At all times within trials, please respond as quickly as possible, while minimizing errors.

TASK 1

During this task, the Display Viewport will appear as a white rectangle on the upper portion of the screen. Upon seeing it appear, [click the mouse button or press the Return key] on the Home Base Viewport as quickly as possible, then prepare for the next cue. This will continue for approximately one minute.

TASK 2

During this task, a series of small rectangles will appear in various regions on the screen. When you are ready to begin, position the pointer within the boundary of the Home Base Viewport and press [the mouse button or Return key]. Upon pressing this key, the small rectangular region will appear somewhere above the Home Base Viewport. Move the pointer using the [mouse or arrow keys) within the boundary of the small rectangular region and press the [mouse button or Return key] as quickly as possible, then move to the next small rectangular region which appears. At the end of each trial, the pointer will be repositioned in the Home Base Viewport (note you may break at this point). Press the mouse button or Return key to initiate the next trial. Continue this procedure for all six trials.

TASK 3 & 5

This task will consist of three sets of twelve trials (a total of 36 trials). When you are ready to begin, depress the [mouse button or Return key] with the pointer within the boundary of the Home Base Viewport. After pressing this key, one of the small rectangular regions within the Keyboard Viewport will turn white. Move as quickly as possible within the boundary of the white rectangular region and press the mouse button or Return key, then move to the next white rectangular region. Within each trial, a series of regions will highlight or turn white. At the end of each trial the

pointer will be re-positioned into the Home Base Viewport. Press the mouse button or Return key to initiate the next trial. Continue this procedure for all 36 trials.

TASK 4

This task will consist of three sets of twelve trials. When you are ready to begin, depress the mouse button or Return key with the pointer within the boundary of the Home Base Viewport. Text will appear in the Display Viewport. Move the pointer within the boundaries of the appropriately labeled rectangular regions in the Keyboard Viewport and proceed typing the text by pressing the mouse button or Return key. Proceed as quickly and accurately as possible. As you select characters, they will be displayed in the Display Viewport. IF MISTAKES ARE MADE, CONTINUE TO TYPE THE REMAINDER OF THE WORD IN SPITE OF THE ERROR, DO NOT ATTEMPT TO MAKE CORRECTIONS. Upon completing the text, the pointer will be moved within the boundary of the Home Base Viewport, indicating the end of the trial. Press the mouse button or Return key to start the next trial. Continue this procedure for the first twelve trials. At this point you will receive a questionnaire. After completing the questionnaire, you will complete another twelve trials and then be given a questionnaire, etc.

APPENDIX I: ANOVA SUMMARY TABLES OBJECTIVE TESTS

TABLE I-1
Gross Words a Minute (GWAM) and
Number Correct for Hard Keyboard Typing Test
ANOVA Summary Table

Source	SS	df	MS	F	p
GWAM:					
Typing Method (M)	1197.09	1	1197.09	13.44	.001*
M x Ss	1958.90	22	89.04		
Number Correct:					
Typing Method (M)	10.67	1	10.67	5.42	.030*
M x Ss	43.33	22	1.97		

TABLE I-2
Input Times for Movement Task I
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	5.08	1	5.08	.19	.671
M x Ss	604.12	22	27.46		
Stimulus Type (S)	.73	1	.73	7.02	.015*
S x Ss	2.28	22	.10		
Input Device (D)	4909.96	1	4909.96	582.65	.000*
D x Ss	185.39	22	8.43		
Keyboard (K)	11.49	1.51	5.74	4.71	.024*
K x Ss	53.65	33.14	1.22		
M x S	.03	1	.03	.34	.568
M x S x Ss	2.28	22	.10		
M x D	10.47	1	10.47	1.24	.277
M x D x Ss	185.39	22	8.43		

TABLE I-2 Continued

Source	SS	df	MS	F	p
M x K	.56	1.51	.28	.23	.733
M x K x Ss	53.65	33.14	1.22		
S x D	.02	1	.02	.10	.749
S x D x Ss	4.67	22	.21		
S x K	.06	1.89	.03	.21	.799
S x K x Ss	6.66	41.58	.15		
D x K	24.71	1.78	12.36	11.75	.000
D x K x Ss	46.26	39.19	1.05		
M x S x D	.00	1	.00	.00	.945
M x S x D x Ss	4.67	22	.21		
M x S x K	.50	1.89	.25	1.64	.208

M x S x K x Ss	6.66	41.58	.15		
M x D x K	.44	1.78	.22	.21	.786
M x D x K x Ss	46.26	39.19	1.05		
S x D x K	.17	1.45	.09	.62	.493
S x D x K x Ss	6.12	31.86	.14		

TABLE I-2 Continued

M x S x D x K	.40	1.45	.20	1.45	.244
M x S x D x K x Ss	6.12	31.86	.14		

TABLE I-3
Input Times for Movement Task I - Simple Effects
ANOVA Summary Table

Source	SS	df	MS	F	p
Keyboard at Input Device:					
Mouse x Keyboard (K)	33.00	1.92	16.50	57.74	.000*
Mouse x K x Ss	12.57	42.32	.29		
Arrow Keys x K	3.2	1.58	1.6	.81	.429
Arrow Keys x K x Ss	87.33	34.72	1.98		

TABLE I-4
Input Times for Movement Task I - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Mouse:					
1-Row vs. 3-Row	27.15	1	27.15	83.68	.000*
1-Row x 3-Row x Ss	7.14	22	.32		
1-Row vs. QWERTY	22.10	1	22.10	73.02	.000*
1-Row x QWERTY x Ss	6.66	22	.30		
3-Row vs. QWERTY	.26	1	.26	1.13	.300
3-Row x QWERTY x Ss	5.07	22	.23		
Arrow Keys:					
1-Row vs. 3-Row	2.62	1	2.62	.90	.353
1-Row x 3-Row x Ss	64.17	22	2.92		
1-Row vs. QWERTY	.02	1	.02	.02	.886
1-Row x QWERTY x Ss	25.24	22	1.15		

TABLE I-4 Continued

3-Row vs. QWERTY	2.15	1	2.15	1.13	.298
3-Row x QWERTY x Ss	41.58	22	1.89		

TABLE I-5
Input Times for Movement Task II
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	13.57	1	13.57	.74	.398
M x Ss	401.62	22	18.26		
Stimulus Type (S)	.74	1	.74	4.36	.049*
S x Ss	3.75	22	.17		
Input Device (D)	3899.92	1	3899.92	512.01	.000*
D x Ss	167.57	22	7.62		
Keyboard (K)	18.77	1.82	9.38	12.66	.000*
K x Ss	32.62	40.04	.74		
M x S	.80	1	.80	4.69	.042*
M x S x Ss	3.75	22	.17		
M x D	9.20	1	9.20	1.21	.284
M x D x Ss	167.57	22	7.62		

TABLE I-5 Continued

Source	SS	df	MS	F	p
M x K	2.09	1.82	1.04	1.41	.256
M x K x Ss	32.62	40.04	.74		
S x D	.94	1	.94	3.32	.082
S x D x Ss	6.22	22	.28		
S x K	.17	1.98	.09	1.06	.354
S x K x Ss	3.61	43.61	.08		
D x K	4.76	1.9	2.38	4.06	.026*
D x K x Ss	25.77	41.84	.59		
M x S x D	.77	1	.77	2.73	.113
M x S x D x Ss	6.22	22	.28		
M x S x K	.08	1.98	.04	.51	.601

M x S x K x Ss	3.61	43.61	.08		
M x D x K	.05	1.9	.03	.04	.952
M x D x K x Ss	25.77	41.84	.59		
S x D x K	.28	1.90	.14	.92	.404
S x D x K x Ss	6.78	41.85	.15		

TABLE I-5 Continued

M x S x D x K	.27	1.90	.13	.86	.424
M x S x D x K x Ss	6.78	41.85	.15		

TABLE I-6
Input Times for Movement Task II - Simple Effects
ANOVA Summary Table

Source	SS	df	MS	F	p
Keyboard at Input Device:					
Mouse x Keyboard (K)	20.82	1.94	10.41	39.34	.000*
Mouse x K x Ss	11.64	42.68	.26		
Arrow Keys x K	2.71	1.89	1.35	1.27	.289
Arrow Keys x K x Ss	46.75	41.55	1.06		
Stimulus Type at Typing Method:					
Non-Finger (NFP) x S	.00	1	.00	.00	.957
NFP x S x Ss	3.75	22	.17		
Finger (FP) x S	1.54	1	1.54	9.04	.006*
FP x S x Ss	3.75	22	.17		

TABLE I-7
Input Times for Movement Task II - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Mouse:					
1-Row vs. 3-Row	15.24	1	15.24	53.25	.000*
1-Row x 3-Row x Ss	6.30	22	.29		
1-Row vs. QWERTY	15.98	1	15.98	55.18	.000*
1-Row x QWERTY x Ss	6.37	22	.29		
3-Row vs. QWERTY	.01	1	.01	.04	.844
3-Row x QWERTY x Ss	4.80	22	.22		
Arrow Keys:					
1-Row vs. 3-Row	1.02	1	1.02	.80	.380
1-Row x 3-Row x Ss	27.88	22	1.27		
1-Row vs. QWERTY	2.66	1	2.66	3.22	.086
1-Row x QWERTY x Ss	18.13	22	.82		

TABLE I-7 Continued

Source	SS	df	MS	F	p
3-Row vs. QWERTY	.39	1	.39	.35	.559
3-Row x QWERTY x Ss	24.12	22	1.10		

TABLE I-8
Input Times for the average of Movement Task I and Movement Task II
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	8.81	1	8.81	.40	.535
M x Ss	487.85	22	22.18		
Stimulus Type (S)	.74	1	.74	9.86	.005*
S x Ss	1.64	22	.07		
Input Device (D)	4390.42	1	4390.42	565.02	.000*
D x Ss	170.95	22	7.77		
Keyboard (K)	14.88	1.48	7.44	9.82	.001*
K x Ss	33.32	32.60	.76		
M x S	.13	1	.13	1.68	.208
M x S x Ss	1.64	22	.07		
M x D	9.83	1	9.83	1.26	.273
M x D x Ss	170.95	22	7.77		

TABLE I-8 Continued

Source	SS	df	MS	F	p
M x K	1.05	1.48	.53	.70	.465
M x K x Ss	33.32	32.60	.76		
S x D	.31	1	.31	2.32	.142
S x D x Ss	2.96	22	.13		
S x K	.01	1.94	.00	.08	.923
S x K x Ss	2.60	42.61	.06		
D x K	12.75	1.9	6.38	.46	.000*
D x K x Ss	29.67	41.83	.67		
M x S x D	.21	1	.21	1.54	.228
M x S x D x Ss	2.96	22	.13		
M x S x K	.24	1.94	.12	2.05	.142

M x S x K x Ss	2.60	42.61	.06		
M x D x K	.20	1.9	.10	.15	.855
M x D x K x Ss	29.67	41.83	.67		
S x D x K	.20	1.75	.10	1.32	.277
S x D x K x Ss	3.27	38.44	.07		

TABLE I-8 Continued

M x S x D x K	.33	1.75	.16	2.21	.129
M x S x D x K x Ss	3.27	38.44	.07		

TABLE I-9
Number Correct for Experimental Task unadjusted
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	.03	1	.03	.07	.788
M x Ss	9.30	22	.42		
Stimulus Type (S)	2.92	1	2.92	10.02	.004*
S x Ss	60.41	22	.29		
Input Device (D)	.42	1	.42	.86	.363
D x Ss	10.72	22	.49		
Keyboard (K)	.13	2	.07	.28	.756
K x Ss	10.31	44	.23		
M x S	.42	1	.42	1.44	.243
M x S x Ss	6.41	22	.29		
M x D	.28	1	.28	.58	.455
M x D x Ss	10.72	22	.49		

TABLE I-9 Continued

Source	SS	df	MS	F	p
M x K	.40	2	.20	.85	.436
M x K x Ss	10.31	44	.23		
S x D	.00	1	.00	.01	.929
S x D x Ss	9.33	22	.423		
S x K	.34	2	.17	1.05	.358
S x K x Ss	7.11	44	.16		
D x K	.63	2	.32	1.54	.227
D x K x Ss	9.06	44	.21		
M x S x D	.087	1	.087	.20	.655
M x S x D x Ss	9.33	22	.423		

M x S x K	.05	2	.02	.15	.861
M x S x K x Ss	7.11	44	.16		
M x D x K	.15	2	.07	.35	.704
M x D x K x Ss	9.06	44	.21		
S x D x K	.34	2	.17	.68	.512
S x D x K x Ss	11.03	44	.25		

TABLE I-9 Continued

M x S x D x K	.47	2	.23	.93	.403
M x S x D x K x Ss	11.03	44	.25		

TABLE I-10
Input Times for Experimental Task unadjusted
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	.575	1	.575	.202	.888
M x Ss	623.80	22	28.35		
Stimulus Type (S)	25.92	1	25.92	10.13	.004*
S x Ss	56.32	22	2.56		
Input Device (D)	4679.07	1	4679.07	474.20	.000*
D x Ss	217.08	22	9.87		
Keyboard (K)	69.61	2	34.80	8.31	.001*
K x Ss	184.39	44	4.19		
M x S	.789	1	.789	.31	.584
M x S x Ss	56.32	22	2.56		
M x D	2.00	1	2.00	.20	.657
M x D x Ss	217.08	22	9.87		

TABLE I-10 Continued

Source	SS	df	MS	F	p
M x K	3.52	2	1.76	.42	.660
M x K x Ss	184.39	44	4.19		
S x D	5.13	1	5.13	1.48	.236
S x D x Ss	76.13	22	3.46		
S x K	2.84	2	1.42	.99	.378
S x K x Ss	62.92	44	1.43		
D x K	42.59	2	21.30	9.76	.000*
D x K x Ss	95.97	44	2.18		
M x S x D	.00	1	.00	.00	.973
M x S x D x Ss	76.13	22	3.46		
M x S x K	2.31	2	1.56	.81	.452

M x S x K x Ss	62.92	44	1.43		
M x D x K	4.77	2	2.39	1.09	.344
M x D x K x Ss	95.97	44	2.18		
S x D x K	.32	2	.16	.13	.882
S x D x K x Ss	56.34	44	1.28		

TABLE I-10 Continued

M x S x D x K	.26	2	.13	.10	.905
M x S x D x K x Ss	56.34	44	1.28		

TABLE I-11
Input Times for Experimental Task unadjusted - Simple Effects
ANOVA Summary Table

Source	SS	df	MS	F	p
<u>Keyboard at Input Device:</u>					
Mouse x Keyboard (K)	55.53	1.88	27.77	33.89	.000*
Mouse x K x Ss	36.05	41.43	.82		
Arrow Keys x K	56.67	1.9	28.34	5.10	.012*
Arrow Keys x K x Ss	244.32	41.72	5.55		

TABLE I-12
Input Times for Experimental Task unadjusted - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Mouse:					
1-Row vs. 3-Row	.28	1	.28	.38	.546
1-Row x 3-Row x Ss	16.36	22	.74		
1-Row vs. QWERTY	44.91	1	44.91	64.82	.000*
1-Row x QWERTY x Ss	15.24	22	.69		
3-Row vs. QWERTY	38.10	1	38.10	37.32	.000*
3-Row x QWERTY x Ss	22.46	22	1.02		
Arrow Keys:					
1-Row vs. 3-Row	51.26	1	51.26	7.51	.012*
1-Row x 3-Row x Ss	150.08	22	6.82		
1-Row vs. QWERTY	2.45	1	2.45	.52	.477
1-Row x QWERTY x Ss	103.10	22	4.69		

TABLE I-12 Continued

Source	SS	df	MS	F	p
3-Row vs. QWERTY	31.30	1	31.30	6.08	.022*
3-Row x QWERTY x Ss	113.29	22	5.15		

TABLE I-13
Input Times for Experimental Task adjusted
ANOVA Summary Table

Source	SS	df	MS	*F*	*p*
Typing Method (M)	11.88	1	11.88	1.16	.293
M x Ss	214.56	21	10.22		
Stimulus Type (S)	29.02	1	29.02	11.72	.003*
S x Ss	52.00	21	2.48		
Input Device (D)	3.45	1	3.45	.88	.359
D x Ss	82.42	21	3.92		
Keyboard (K)	77.70	1.93	38.85	11.51	.000*
K x Ss	145.16	41.54	3.38		
M x S	1.99	1	1.99	.80	.380
M x S x Ss	52.00	21	2.48		
M x D	1.77	1	1.77	.45	.509
M x D x Ss	82.42	21	3.92		

TABLE I-13 Continued

Source	SS	df	MS	*F*	*p*
M x K	6.50	1.93	3.25	.96	.388
M x K x Ss	145.16	41.54	3.38		
S x D	1.91	1	1.91	.57	.457
S x D x Ss	69.86	21	3.33		
S x K	2.70	1.74	1.35555	.93	.391
S x K x Ss	62.25	37.49	1.45		
D x K	10.81	1.89	5.41	3.16	.056
D x K x Ss	73.67	40.64	1.71		
M x S x D	.33	1	.33	.10	.755
M x S x D x Ss	69.86	21	3.33		
M x S x K	2.68	1.74	1.34	.93	.393

M x S x K x Ss	62.25	37.49	1.45		
M x D x K	5.43	1.89	2.72	1.58	.218
M x D x K x Ss	73.67	40.64	1.71		
S x D x K	.16	1.89	.08	.06	.933
S x D x K x Ss	55.87	40.74	1.30		

TABLE I-13 Continued

M x S x D x K	.29	1.89	.15	.11	.884
M x S x D x K x Ss	55.87	40.74	1.30		

TABLE I-14
Input Times for Experimental Task adjusted - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
1-Row vs. 3-Row	56.18	1	56.18	17.88	.000*
1-Row x 3-Row x Ss	65.97	21	3.14		
1-Row vs. QWERTY	.41	1	.41	.14	.716
1-Row x QWERTY x Ss	63.46	21	3.02		
3-Row vs. QWERTY	59.51	1	59.51	14.73	.001*
3-Row x QWERTY x Ss	84.86	21	4.04		

APPENDIX J: ANOVA SUMMARY TABLES SUBJECTIVE TESTS

TABLE J-1
Subjective Ratings for Statement 1
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	26.67	1	26.67	7.60	.012*
M x Ss	70.20	20	3.51		
Input Device (D)	17.73	1	17.73	5.44	.030*
D x Ss	65.20	20	3.26		
Keyboard (K)	10.58	2	5.29	2.51	.094
K x Ss	84.00	40	2.10		
M x D	2.28	1	2.28	.70	.413
M x D x Ss	65.20	20	3.26		
M x K	1.00	2	.50	.24	.788
M x K x Ss	84.40	40	2.10		
D x K	14.60	2	7.30	8.59	.001*
D x K x Ss	34.00	40	.85		

TABLE J-1 Continued

Source	SS	df	MS	F	p
M x D x K	3.34	2	1.66	1.96	.154
M x D x K x Ss	34.00	40	.85		

TABLE J-2
Subjective Ratings for Statement 1 - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Arrow Keys:					
1-Row vs. 3-Row	19.88	1	19.88	19.59	.000*
1-Row x 3-Row x Ss	20.30	20	1.02		
1-Row vs. QWERTY	17.27	1	17.27	13.87	.001*
1-Row x QWERTY x Ss	24.91	20	1.25		
3-Row vs. QWERTY	.09	1	.09	.07	.797
3-Row x QWERTY x Ss	26.91	20	1.35		

TABLE J-3
Subjective Ratings for Statement 2
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	.00	1	.00	.00	.990
	127.80	20	6.39		
Input Device (D)	7.47	1	7.47	3.62	.072
	41.40	20	2.06		
Keyboard (K)	6.94	2	3.47	1.65	.205
	84.40	40	2.11		
M x D	.26	1	.26	.13	.727
M x D x Ss	41.40	20	2.06		
M x K	.64	2	.32	.15	.860
M x K x Ss	84.40	40	2.11		
D x K	10.02	2	5.01	3.70	.033*
D x K x Ss	54.00	40	1.35		

TABLE J-3 Continued

Source	SS	df	MS	F	p
M x D x K	5.60	2	2.80	2.07	.140
M x D x K x Ss	54.00	40	1.35		

TABLE J-4
Subjective Ratings for Statement 2 - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Arrow Keys:					
1-Row vs. 3-Row	7.88	1	7.88	6.77	.017*
1-Row x 3-Row x Ss	23.30	20	1.17		
1-Row vs. QWERTY	15.93	1	15.93	10.13	.005*
1-Row x QWERTY x Ss	31.46	20	1.57		
3-Row vs. QWERTY	1.40	1	1.40	.714	.408
3-Row x QWERTY x Ss	39.26	20	1.96		

TABLE J-5
Subjective Ratings for Statement 10
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	10.51	1	10.51	.83	.373
	253.80	20	12.69		
Input Device (D)	.33	1	.33	.18	.676
	36.40	20	1.82		
Keyboard (K)	1.44	2	.72	1.30	.285
	22.00	40	.55		
M x D	.33	1	.33	.18	.676
M x D x Ss	36.40	20	1.82		
M x K	1.16	2	.58	1.05	.359
M x K x Ss	22.00	40	.55		
D x K	3.78	2	1.89	4.33	.020*
D x K x Ss	17.60	40	.44		

TABLE J-5 Continued

Source	SS	df	MS	F	p
M x D x K	1.32	2	.66	1.52	.231
M x D x K x Ss	17.60	40	.44		

TABLE J-6
Subjective Ratings for Statement 10 - Simple Comparisons
ANOVA Summary Table

Source	SS	df	MS	F	p
Arrow Keys:					
1-Row vs. 3-Row	2.55	1	2.55	4.91	.038*
1-Row x 3-Row x Ss	10.38	20	.52		
1-Row vs. QWERTY	4.49	1	4.49	8.76	.008*
1-Row x QWERTY x Ss	10.26	20	.51		
3-Row vs. QWERTY	.27	1	.27	.79	.384
3-Row x QWERTY x Ss	6.91	20	.35		

TABLE J-7
Subjective Ratings for Statement 11
ANOVA Summary Table

Source	SS	df	MS	F	p
Typing Method (M)	6.38	1	6.38	.59	.453
M x Ss	217.80	20	10.89		
Input Device (D)	1.00	1	1.00	.80	.382
D x Ss	25.00	20	1.25		
Keyboard (K)	1.64	2	.82	1.07	.354
K x Ss	30.80	40	.77		
M x D	.18	1	.18	.15	.706
M x D x Ss	25.00	20	1.25		
M x K	2.10	2	1.05	1.36	.268
M x K x Ss	30.80	40	.77		
D x K	1.74	2	.87	2.19	.125
D x K x Ss	16.00	40	.40		

TABLE J-7 Continued

Source	SS	df	MS	F	p
M x D x K	.02	2	.01	.01	.987
M x D x K x Ss	16.00	40	.40		

APPENDIX K: MEANS AND STANDARD DEVIATIONS

TABLE K-1
Gross Words a Minute (GWAM) and
Number Correct for Hard Keyboard Typing Test
Means and Standard Deviations

GWAM

	Mean	Standard Deviation
Finger Placement typists	39.79	12.38
Non-Finger Placement typists	25.67	4.99

Number Correct

	Mean	Standard Deviation
Finger Placement typists	3.17	1.59
Non-Finger Placement typists	1.83	1.19

TABLE K-2
Input Times for Movement Task I
Means and Standard Deviations
Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	7.37	1.59	6.27	1.03	6.38	1.23
Arrow Keys	14.59	2.92	14.64	2.34	14.49	2.51

Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	7.29	1.27	6.20	1.17	6.36	1.24
Arrow Keys	14.44	2.64	14.73	2.42	14.25	2.36

TABLE K-3
Input Times for Movement Task I
Means and Standard Deviations
Non-Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	7.26	0.57	6.24	0.72	6.25	0.73
Arrow Keys	14.88	1.94	15.62	2.47	15.21	2.31

Non-Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	7.13	0.61	6.08	0.83	6.21	0.61
Arrow Keys	14.99	1.75	15.24	2.62	15.08	2.52

TABLE K-4
Input Times for Movement Task II
Means and Standard Deviations
Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.68	1.07	5.71	0.91	5.76	1.06
Arrow Keys	13.63	2.09	13.01	2.21	13.18	2.30

Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.63	1.10	5.66	0.81	5.89	0.92
Arrow Keys	13.04	1.84	12.80	2.24	12.69	1.80

TABLE K-5
Input Times for Movement Task II
Means and Standard Deviations
Non-Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.66	0.44	5.97	0.72	5.74	0.62
Arrow Keys	13.90	1.58	13.96	2.37	13.69	2.14

Non-Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.55	0.60	5.99	0.72	5.87	0.74
Arrow Keys	13.96	1.71	13.94	2.14	13.64	2.06

TABLE K-6

Input Times for the Average of Movement Tasks I & II

Means and Standard Deviations

Finger Placement Typists - Words

	1-Row Mean	SD	3-Row Mean	SD	QWERTY Mean	SD
Mouse	7.02	1.31	5.99	0.94	6.07	1.08
Arrow Keys	14.11	2.45	13.82	2.24	13.83	2.36

Finger Placement Typists - Non-Words

	1-Row Mean	SD	3-Row Mean	SD	QWERTY Mean	SD
Mouse	6.96	1.16	5.93	0.97	6.13	1.06
Arrow Keys	13.74	2.23	13.76	2.23	13.47	2.03

TABLE K-7
Input Times for the Average of Movement Tasks I & II
Means and Standard Deviations
Non-Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.96	0.44	6.11	0.68	5.99	0.61
Arrow Keys	14.39	1.71	14.79	2.37	14.45	2.18

Non-Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	6.84	0.51	6.04	0.71	6.04	0.63
Arrow Keys	14.47	1.69	14.59	2.34	14.36	2.23

TABLE K-8
Number Correct for Experimental Task - unadjusted
Means and Standard Deviations
Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	5.58	0.67	5.92	0.29	5.83	0.39
Arrow Keys	5.92	0.29	5.92	0.29	5.83	0.39

Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	5.50	0.52	5.50	0.67	5.42	0.79
Arrow Keys	5.58	0.52	5.67	.49	5.67	0.65

TABLE K-9
Number Correct for Experimental Task - unadjusted
Means and Standard Deviations
Non-Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	5.67	0.65	5.92	0.29	5.67	0.49
Arrow Keys	5.92	0.29	5.75	0.45	5.75	0.45

Non-Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	5.67	0.49	5.58	.52	5.75	.45
Arrow Keys	5.83	0.39	5.58	0.67	5.50	0.91

TABLE K-10
Input Times for Experimental Task - unadjusted
Means and Standard Deviations
Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	8.78	1.23	8.63	1.39	7.44	1.53
Arrow Keys	15.56	2.71	17.60	3.92	16.20	3.24

Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	9.97	1.29	9.57	1.45	8.25	1.38
Arrow Keys	16.45	2.86	18.09	3.61	16.12	2.91

TABLE K-11
Input Times for Experimental Task - unadjusted
Means and Standard Deviations
Non-Finger Placement Typists - Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	8.42	0.92	8.76	1.24	7.24	1.30
Arrow Keys	15.98	2.01	17.38	3.16	16.52	2.54

Non-Finger Placement Typists - Non-Words

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	9.38	1.08	9.16	1.07	8.15	1.27
Arrow Keys	16.46	1.85	17.24	3.08	16.90	3.01

TABLE K-12
Input Times for Experimental Task - adjusted
Means and Standard Deviations

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	12.16	0.82	12.91	0.52	12.06	1.22
Arrow Keys	12.51	0.57	13.91	0.21	12.96	0.25

Stimulus Type

	Mean	Standard Deviation
Words	12.33	0.92
Non-Words	13.18	0.47

TABLE K-13
Subjective Ratings - Question 1
Means and Standard Deviations
Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	3.25	1.76	3.92	1.68	4.25	1.66
Arrow Keys	3.92	1.08	2.75	0.97	3.00	1.41

Non-Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	4.67	1.50	4.25	1.71	4.42	1.56
Arrow Keys	4.75	1.29	3.25	1.36	3.25	1.71

TABLE K-14
Subjective Ratings - Question 2
Means and Standard Deviations
Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	3.67	1.61	3.25	1.66	2.58	1.16
Arrow Keys	2.75	0.87	3.83	1.19	3.58	1.68

Non-Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	2.58	1.73	2.92	2.02	2.92	1.51
Arrow Keys	2.75	1.71	3.42	1.78	4.17	1.90

TABLE K-15
Subjective Ratings - Question 10
Means and Standard Deviations
Finger Placement Typists

	1-Row Mean	SD	3-Row Mean	SD	QWERTY Mean	SD
Mouse	4.58	1.83	5.17	1.34	5.42	1.31
Arrow Keys	5.25	1.42	4.75	1.36	4.17	1.80

Non-Finger Placement Typists

	1-Row Mean	SD	3-Row Mean	SD	QWERTY Mean	SD
Mouse	4.83	1.75	4.67	2.10	4.75	2.09
Arrow Keys	5.08	1.51	4.58	1.62	4.67	1.72

TABLE K-16
Subjective Ratings - Question 11
Means and Standard Deviations
Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	2.92	1.51	2.83	1.34	2.67	1.15
Arrow Keys	2.83	1.40	3.33	1.50	3.67	1.83

Non-Finger Placement Typists

	1-Row		3-Row		QWERTY	
	Mean	SD	Mean	SD	Mean	SD
Mouse	2.92	1.68	3.25	2.05	3.17	1.90
Arrow Keys	2.75	1.60	3.25	1.66	3.17	1.53

TABLE K-17
Subjective Rankings
Means

	1-Row Mean	3-Row Mean	QWERTY Mean
Mouse	4.13	4.04	1.10
Arrow Keys	4.38	5.46	1.90

U.S. Government Printing Office 1996 750-071/40007